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CAMERON STATION, ALEXANDRIA, VIRGINIA

ELECTRICAL ENGINEERING RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

Austin, Texas

ARPA REPORT NO. 1

GEOFIELD MEASUREMENTS DURING FISH BOWL

Part I: Operation and Instrumentation

Annual Report

1 April 1962 - 31 March 1963

by

George Hopkins, Jr.

Francis X. Bostick, Jr.

OFFICE OF NAVAL RESEARCH

Washington, D. C.

288400

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ARPA Order No. 215-62

Project Code No.: 8200

Contract Nonr 375(14)

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ABSTRACT

The operational phases of the Electrical Engineering Research Laboratory participation in the FISH BOWL test series are detailed. A complete description is given of the equipment and data acquisition techniques of both the fixed station at Austin, Texas and the mobile station at Puerto Rico. No data or results are included in this report.

I. INTRODUCTION

This report covers the interval from 1 April through 31 December 1962. During that period the Electrical Engineering Research Laboratory completed the operational phases of a series of geomagnetic measurements made in conjunction with the FISH BOWL atomic test series. Analysis of the data acquired is now nearing completion; the data and the results of that analysis will be presented in the second report of this series.

A. Background

The University of Texas Electrical Engineering Research Laboratory has been engaged in a continuing program of measurement and analysis of the fluctuations of the earth's natural electric and magnetic fields for several years. Emphasis in this research has been concentrated on the variations below 20 cps. In the course of these investigations, the Electrical Engineering Research Laboratory has constructed a fixed station at Austin, Texas (97°43'35"W, 30°23'10"N), capable of continuous recording of two horizontal electric field components and three quadrature magnetic field components with highly accurate timing information; a mobile field unit has been equipped which duplicates the capabilities of the fixed station.

The greater portion of the continuing program has been financed by the Office of Naval Research under contracts Nonr 375(01) and Nonr 375(14), but certain special projects undertaken for the Air Force Cambridge Research Laboratories under contract AF 19(604)-8513 have also contributed significantly. Outfitting of the mobile unit was financed jointly by the Advanced

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Research Projects Agency and the Office of Naval Research.

When the schedules for FISH BOWL became definite, this Laboratory was asked by   ARPA to monitor the perturbations in the earth's electromagnetic fields in the .001 - 20 cps band during the high altitude tests.   Both the fixed station already in operation at Austin and the mobile unit were to be used.   Puerto Rico was selected as the field site, due to a scarcity of geomagnetic monitors in the Caribbean area. Financing was by ARPA through the existing ONR contract, Nonr 375(14).

Throughout February, March, April, and the first part of May, 1962, the mobile unit was modified and its capabilities increased. Some new equipment was purchased, but a larger amount, not commercially available, was built by this Laboratory.   This apparatus was then tested and installed.   Previous field trips had furnished valuable experience and indicated numerous instrument modifications, and these together with a large design effort resulted in a vastly improved system, both in the mobile unit and at the fixed station.

B. Puerto Rican Site Selection

In March, George Hopkins, the engineer in charge of the field work, went to Puerto Rico for four days to make contact with the personnel and officers at the San Juan Naval Station who would be supporting the field work.   Liaison was to be through the Area Public Works Office of the 10th and 11th Naval Districts.   Commander C. L. Hayen, the Assistant Area Public Works Officer, proved to be exceptionally helpful then and during

the test series. Indeed, the project could hardly have been successful without his efforts in satisfying our sometimes unusual requests.

One of the primary objectives of the preliminary trip was to locate a site for the equipment. The Real Estate Section of the APWO was consulted and with their assistance seven potential sites were investigated. These were:

1. the Ramey Air Force Base receiver site at Aguada;

2. a site on the Ramey AFB main grounds;

3. the Ramey AFB transmitter site at Isabela;

4. the Puerto Rican National Guard Camp Tortuguero near Vega Baja;

5. Punta Talega, near Loíza Aldea about 10 miles east of San Juan;

6. the Roosevelt Roads Naval Station; and

7. Punta Yeguas, near Yabucoa on the southeast coast.

The primary requirements were remoteness from vehicular traffic, electric power generating plants, urban areas, and other possible noise sources; accessibility to a support facility; and a land area for the sensors as level and open as possible.

Two days were spent with Mr. Allan Payne of the Real Estate Office inspecting the prospective sites. The best choice appeared to be beside the air strip at the Puerto Rican National Guard Camp at Tortuguero. The airstrip at Camp Tortuguero was built for auxiliary use during the Second World War, and is now used only occasionally by light aircraft. The area off the east end of the runway is clear, level, and open; an unused paved taxiway provided a parking place for the field unit; and, perhaps best of all,

one of the guards from Camp Tortuguero lived at the southeast corner of
the runway and could watch over the equipment when it had to be left un-
attended. This last was a very important factor as anything left untended
in Puerto Rico is considered abandoned and may be picked up by the first
person that happens by.

Camp Tortuguero is about 30 miles from the Naval Station at
San Juan. The connecting road, although heavily traveled, is reasonably
good. The distance from the air strip to the nearest generating station is
about 20 miles. This seems to be about as far as one can get from a
generating station on the island.   Arrangements were made with the Puerto
Rican National Guard through the APWO for use of the air strip property
and access to Camp Tortuguero. Colonel Angel H. Ruiz, the PRNG Assistant
Adjutant General, directed the personnel on duty at Camp Tortuguero to
provide all possible assistance, which they did very willingly.

C. The Field Trip

On 6 May 1962, the field equipment left Austin for New Orleans
for shipment to Puerto Rico. It consisted of the mobile unit - a 35 foot bus -
which carried the instrumentation and supplies, and a 15 kw diesel-driven
generator pulled by a truck tractor; the drivers were George Hopkins and
Technical Staff Assistants William A. Martin and C. W. Brewer. Shipment
to Puerto Rico was arranged and financed by the Chicago ONR Branch Office
and was via the Waterman Steamship Company SS Monarch of the Seas. On
arrival in New Orleans on 7 May, a considerable amount of negotiation

and argument with representatives of Waterman ensued -- caused by the instrumentation and supplies in the bus, which they insisted on handling separately. A compromise solution was found and a portion of the gear was repacked in a steel van. The personnel returned to Austin during 12-13 May in the truck tractor, after repacking and shipping arrangements were completed.

On 14 May, the field crew consisting of George Hopkins, the Engineer in Charge, and Technicians W. A. Martin and C. W. Brewer, left by plane for San Juan. The ship carrying the equipment arrived 15 May and on 19 May the mobile unit was in place at Camp Tortuguero. The first measurements--of the electric field-- were begun 23 May. The vertical magnetic field channel went into operation on 30 May. These three channels were actuated first because their instrumentation had been used and perfected on previous operations. Even so, eleven days of very intensive effort were required to lay out the sensors, calibrate the instruments, and solve the noise and repair problems induced by an inoperative period followed by shipment. Also, there are always a variety of noise problems peculiar to each site which must be detected, isolated, and eliminated before any reliance can be placed on the data. The last two instrumentation channels, monitoring the horizontal magnetic field, operated sporadically from 7 June and became fully operative 19 June. These two channels included new mumetal-core coils and amplifiers which were being used for the first time, and required a very large amount of experimentation and adjustment before they would produce data in which confidence could be placed.

Over the period 23 May through 6 June the system was in operation recording the natural field variations during working hours, and on a 24-hour basis during the test attempt of 4 June. Power was supplied by the diesel generator until 27 June when a connection was made to an old and rather temperamental feeder line near the airstrip. The commercial power averaged one outage a day: it was not sufficiently reliable to be used during the tests, so the equipment was put on the diesel unit during countdowns.

Operations were complicated by the fact that the personnel were forced to live in San Juan until 6 June because of housing shortages in Vega Baja and Puerto Nuevo, a fishing village next to Camp Tortuguero. The drive between San Juan and Tortuguero, although only 30 miles, took at least an hour and forty-five minutes each way because of the heavy traffic. The Puerto Rican summer season was well under way, so all the local housing was occupied in the Puerto Nuevo Area. Camp Tortuguero has housing facilities for only the caretaker personnel. However, through the efforts of Captain Juan Parés, the Camp Security Officer, contact was made with Sr. Angel Malendez of Vega Baja, who made himself responsible for housing the group. After some looking about, he rented us his own house in Puerto Nuevo, placing the living quarters within two miles of the site.

From 7 June through 26 June, the equipment operated on a 24-hour basis except when the personnel had to go into San Juan for supplies or the diesel generator had to be stopped for maintenance. From 27 June through 2 August, operation was almost continuous.

C. W. Brewer returned to Austin 1 June and W. A. Martin on 8 June. They were replaced on 8 June by Francis Bostick, the Engineer in Charge of the Electrical Engineering Research Laboratory geofield program. Mr. Bostick remained until 2 July when he was replaced by Henry I. Gonzales, a Technical Staff Assistant, who stayed until the first phase of the test series was rather abruptly terminated on the morning of 26 July. Operations continued through 2 August, when the mobile unit was moved into a storage shed at Camp Tortuguero; the sensors were left in place in the field under the care of the Camp Tortuguero guard. All the personnel returned to Austin on 4 August.

When the second part of FISH BOWL was scheduled, George Hopkins and Henry Gonzales returned to Puerto Rico to prepare the equipment, arriving 1 October. The instruments were in operation again 3 October. Five orthogonal components of the natural field were monitored continuously through 6 November. The equipment was then packed and the mobile unit driven to the Army Terminal in San Juan on 9 November. It left for New Orleans 14 November aboard the Naval Supply Ship Short Splice.

Henry Gonzales returned to Austin 12 November. George Hopkins took care of the various details of terminating the project, then flew to New Orleans 19 November to take delivery of the equipment. He was met by W. A. Martin, who had driven a truck tractor down from Austin to pull the generator trailer. Unloading was delayed by the Thanksgiving holidays, so the equipment was not ready to leave until late 23 November. The units arrived in Austin on 25 November.

D. Participation

Both the base station in Austin and the field unit in Puerto Rico monitored five field components (E_x, E_y, H_x, H_y, and H_z), which could be recorded on either paper chart or magnetic tape along with timing information. Both units were in operation during every countdown, and in sustained operation for 24 hours before and after each successful test. The only failure was an accidental erasure of the H_z channel of the Austin station tape record following the 9 July test. Information was recorded on magnetic tape for at least 30 minutes before and after H-0 and on paper chart for at least 24 hours before and after H-0.

In addition, the natural geofield was monitored almost continually from 23 May through 2 August and again from 3 October through 6 November, in both Austin and Puerto Rico. A great amount of information was gained in that way on the background micropulsations and on the relationship between the signals at two widely separated points (approximately 2380 miles).

E. Terminology

A standard terminology is used in the original records and throughout this report. It is based on an orthogonal coordinate system in which the positive X axis is directed toward geographic North, the positive Y axis is directed toward geographic East, and the positive Z axis is directed downwards: a right-handed system.

The electric field components are designated E_x, E_y, and E_z, and are considered positive when directed in the positive X, Y, and Z

directions. They are defined according to the standard usage of electric field intensity, being positive in the direction of decreasing potential energy: a positive E_x, therefore, represents a voltage drop from the South to the North. The units normally used in geomagnetic work are millivolts/kilometer or microvolts/kilometer. On the original Puerto Rican records the calibration is in terms of microvolts/1000 ft. because of the electrode spacing.

The magnetic field components are designated H_x, H_y, and H_z, and defined according to conventional usage for the magnetic field intensity vector. Their directions follow those of the electric field components. The usual unit is the gamma, which is 10^{-5} gauss. The Austin records follow this practice, but the original Puerto Rican records are calibrated in terms of coil output voltage in microvolts. A conversion to gamma units was made later.

II. THE SITES

A. Austin

The station at Austin, Texas has been in existence since 1959. It is located on the grounds of The University of Texas Balcones Research Center on the northern city limits of Austin and about two miles from the edge of the developed areas. The geographic coordinates are approximately 97°43'35"W, 30°23'10"N -- the location of the station is marked with a circle in Figure 1.

Austin is located just east of the Balcones Fault, which passes about 2000 yds west of the measurement site on an approximate North-South line. From this fault to the Gulf Coast, some 170 miles southeast, there is a quite deep sedimentary deposit containing some limestone and other sedimentary rock formations. The Edwards Plateau, underlain with Edwards limestone, extends westward from the fault. The Llano uplift, a plug some 50 miles across composed of basement granite, is centered about 70 miles West by Northwest. At the site of the sensors the land is relatively level. The soil is black loam with some clay overlaying a solid sheet of Austin limestone which is about three to six feet below the surface.

There is more electrical noise at this site than is desirable, the principal contributor being the nearby city of Austin. Another major noise source is the chain of Lower Colorado River Authority Dams spotted up the Colorado River and separated from the Laboratory by 7 to 55 miles. The electrical noise from the city appears random in nature, occurring above

1 to 2 cps. Its amplitude is small enough so that it can be filtered out easily for low frequency observations. The power houses at the several dams contribute large pulse-type noise similar to that from lightning, but of longer duration, which is relatively rare at this distance and is probably associated with switching or load change transients. Figure 2 shows photographs of the Austin site and its equipment.

B. Puerto Rico

Camp Tortuguero, where the Puerto Rican station was located, is approximately in the center of the northern coast of the island. Its location is marked in Figure 3. The coordinates as read from the USCGS map are 18°29'11"N, 66°25'33"W. The distance from the shore to the north electrode was about 2000 ft; the coils were about 2700 ft. from the shore. The land is quite flat from the coast to the hills running parallel to the coast about five miles inland. The depth of the sea increases rapidly to about 27,000 ft. in the Puerto Rican Trench, which passes approximately 65 miles north of the island in a more or less East-West direction. Figure 4, taken from Naval Hydrographic Office Map No. 1290, shows the surrounding Caribbean area. The soil was red clay containing broken rocks. There was a little rain almost every day, which kept the soil damp much of the time.

Electrical interference at this site was negligible. Although a 2300 volt feeder transmission line passed within 30 feet of the instrumentation, it terminated in another 200 feet; the only users were our instrumentation and the base guard's house. The normal power system ground was

disconnected and the power system grounded to the instrument ground to eliminate interference from that source. The nearest generating plant was about 20 miles away. The major noise contributors were the cattle grazing in the grass-covered land about the sensors. They would cause spikey-appearing disturbances by stepping on the electrode lines or on the H_z coil. This was not a very great problem, however, and the cattle were never in the fields during a test. Figure 5 shows two photographs taken at this site.

III. COMMUNICATIONS

April Weather was, of course, the primary source of countdown information. Reception in Austin was reasonably good after 2300 to 2400 CST (local time). The 15 Mc frequency became operational first, then 12 Mc later in the night. A National RAO-7 receiver was used -- the single sideband transmissions were demodulated either with the BFO or by injecting a carrier at the antenna with a BC 221-AH frequency meter.

In Puerto Rico, reception was marginal from about 2300 to 0200 AST (local time), and not really satisfactory after that. An RAO-7 receiver with a sideband converter was tried at first, but proved completely inadequate. The Naval Communications Station at San Juan then lent us a Hammerlund SP-600X (R-274), which IND-MAN 10 was good enough to align after a certain amount of negotiation. This, in combination with the sideband adapter, worked reasonably well. A 230-foot long wire antenna, supported by 40 ft. bamboo

poles, was used. The main difficulties were interference from teletype and CW stations operating adjacent in frequency to April Weather; and Radio Moscow, which would overwhelm the 12 Mc transmissions about 0400 AST on some mornings.

The 15 Mc transmissions would ordinarily become usable around 2300-2400 AST, but would quickly fade out. Around 0100-0200 AST the Mc transmissions would become usable; then 6 Mc about 0500 AST and 4 Mc about 0800 AST.

At the beginning of FISH BOWL a short explanation of code words to be used by April Weather was sent out. These signals were apparently used only during the first test. It is recommended that in any later test series there be a set of code words established and followed so that the distant participants may be aware of what is taking place, particularly with regard to postponements and rescheduling. Information on rescheduling was often given only once and with little or no warning, which frequently resulted in its being missed during periods when the signal was readable only part of the time. This situation was improved somewhat toward the end of the series, but still left much to be desired. Frequently, the only way to find out what was going on was to tune in mainland broadcast stations which would usually give the new test date and the reason for the postponement. However, since this information was unofficial there was some doubt as to its trustworthiness, which resulted in a considerable unnecessary loss of sleep. The "negative" signal, particularly early in the summer before the participants had become

so accustomed to it, likewise caused confusion because it had not been defined in advance.

It was next to impossible to get verification of schedule changes in Puerto Rico, which was unfortunate but unavoidable. The Vega Baja telephone office, eight miles from the site, containing the city's only public phone, was closed from 2200 to 0700. The only telephone at Camp Tortuguero was in the Supply Office, closed from 1600 to 0800, and Puerto Nuevo's only telephone, in Roberto's Bar on the beach, was available only when the bar was open. That was only when Roberto felt the urge: seldom. This probably saved time in the long run, since it often took longer to complete a long distance call than it did to drive to see the party called.

A microwave relay tower, part of the communications link between Ramey AFB and San Juan, was located midway down the airstrip. It is maintained by the Federal Electric Corporation. It was found that no equipment was available to patch into the system at Tortuguero, which eliminated the possibility of using it for a more direct link.

IV. SENSORS

A. The Electrodes

The Austin and Puerto Rico installations used identical electrodes built by this Laboratory as the result of extensive experimentation.[1] Each electrode consists of a pyrex filter crucible filled with a saturated cadmium chloride buffer electrolyte in which a pure cadmium rod is suspended.

Contact with the ground is made through the bottom of the crucible, a fine ceramic filter. A photograph and a detailed drawing of the electrode are presented as Figure 6. The electrode is particularly well suited for mobile station use because the electrode-ground contact potential stabilizes quickly, very little excavation is needed for its installation, and its small size, approximately 1-3/4 in. in diameter and 2-7/8 in. high, makes it easy to handle. For a permanent installation, buried lead electrodes of large surface area are probably prefereable since the lead electrodes would require little or no maintenance.

Contact potential differences of less than 10 mv are usual where the soil in which the two electrodes are placed is similar in composition; differences of less than 1 mv are common. This potential, ordinarily quite stable, can be easily canceled by inserting a series bucking voltage - the reason it should be canceled is explained in the Noise Section. The contact potential voltage has never been found greater than 50 mv for electrodes in good condition. It is sufficiently stable to allow measurments down to the 0.001 cps range without electrode interference, provided the electrodes are protected against flooding brought on by rain or other causes.

The electrodes will usually function a month or more without servicing, the need for which is indicated by a rising contact potential and/or an increasing resistance to ground. Occasionally offsets on the data will be caused by a crack developing between the electrode and the ground as the latter dries out -- this is unusual. It usually suffices to change the electrode

fluid and scrape off the electrode. Ordinarily only occasional additions of

electrolyte are required, say once each month or two, necessitated by the

slow loss of liquid through the filter or by the gradual dilution of the electro-

lyte with ground water.

At the fixed station in Austin the electrodes are embedded in the

ground at the bottom of concrete tile wells about 30 in. deep, as is shown

in Figure 7. The tops of the holes are stopped with 6 in. thick styrofoam

plugs and closed with a wooden cover. During dry periods, a few gallons of

water is poured into the holes every three or four weeks to keep the ground

moist.

At Puerto Rico the electrodes were placed in holes 6 to 18 inches

deep -- just deep enough to get through the vegetation to undisturbed soil.

A thin mud was mixed in the bottom of each hole and the electrode carefully

imbedded in it. A wooden cover was placed over the hole to protect the

electrode physically, shield it from the sun, and retard temperature changes.

This installation naturally does not result in as stable an electrode as does

the more elaborate one at Austin, but the stability has proved adequate. The

cover is finished with red fluorescent paint to aid in finding it in the brush.

In some installations it is necessary to mix one or two cups of common salt

(NaCl) with the mud to lower the electrode resistance to an acceptable value:

the input filter requires a source impedance of 600 ohms. This value has

never been difficult to obtain. In Puerto Rico the resistance between two

electrodes remained in the range from 250 to 500 ohms, which is common

and the same as that in Austin. The electrodes in Puerto Rico were salted. Those in Austin are not. Water was put on the Puerto Rican electrodes when the soil became too dry from lack of rain -- this occurred during the last part of the test series when the rainy season had ended.

At Austin, connection between the electrodes and the instruments is made with No. 14 single-conductor, solid, direct burial cable, Type R, insulated with two layers of neoprene compound. The wires are buried and have been in use about four years.

The Puerto Rican electrodes were connected to the instruments with ordinary stranded, vinyl-insulated No. 20 hook-up wire, Belden 8523-1000 (MIL-W-76A). This wire is cheap, easy to handle, and has proved satisfactory for temporary mobile use over a period of 3 years. The insulation will usually endure exposure for periods up to about three months. The wire was weighted but not buried.

There are several crucial factors to consider in connecting the electrodes. One of the most important is that even very short sections of the wires must not be free to move. A very small motion of one of the wires in the earth's magnetic field will induce a voltage comparable in magnitude and often in appearance with the natural field variations. Such a motion may be caused directly by the wind, or indirectly through wind vibration of a tree, bush, or weed near which the wire passes. The mobile unit cables were stretched tight and weighted at frequent intervals with rocks or dirt. This method is preferable to burial in field work because it requires much less

time and effort. It has proved satisfactory.

The wire-to-ground insulation resistance is another important factor, as a sufficient decrease will introduce an extra electrode into the system. The result will be sudden offsets or large, slow variations in the data as the moisture, pressure of the wire against the ground, and other factors vary. Occasional checks of the resistance to ground are necessary to detect insulation deterioration. It is best to perform them while the system is wet with rain or dew. It has been found that a wire-to-ground resistance greater than one megohm is usually adequate. Wire joints should be minimized and those present carefully wrapped and supported so they will not stand in water.

Neither the fixed nor the mobile station uses shielded lead-in cable. It has been found unnecessary at frequencies less than 20 cps.

A plot showing the arrangement of the sensors at Austin, made from surveying data, is given in Figure 8. The electrodes are oriented on geographic coordinates and are approximately 1100 ft. apart.

The Puerto Rican sensor arrangement is shown in Figure 9. This system was initially oriented through use of a transit compass, paying close attention to the magnetic declination. A series of six solar sights were made 16 July 1962 to find the true bearing of the North-South line, which was computed as N 00°0. 97' E. This value should be accurate to $\pm 2'$. Distances were measured with a stadia rod, which is accurate to about 0. 5%. The North and South electrodes were moved 155 ft. North on 16 July 1962,

the action having been forced by an increase in electrode resistance and contact potential which could not otherwise be remedied. Both the old and the new electrode locations are shown on the plat.

B. The Coils

Three air-core coils, in use since 1960,[2] sense the magnetic field variations at the Austin station. Photographs of these coils are shown in Figure 10. Each is wound with approximately 15, 000 turns of AWG 28 nyclad magnet wire and has a 2-meter mean diameter. The windings have electrostatic shields. An equivalent circuit for these coils and a tabulation of the parameters of each is given in Figure 11.

The relation between the voltage induced in a coil and the magnetic field inclosed by the windings may be expressed as

$$E_c(jw) = \frac{K_c \Gamma(jw) jw}{2\pi} , \qquad (1)$$

where $E_c(jw)$ is the Fourier Transform of the induced voltage in microvolts, $\Gamma(jw)$ is the Fourier Transform of the field intensity in gamma, K_c is the coil constant, and w is the frequency of the signal in radians/sec. Using the number of turns listed in the table of Figure 11, the air-core coil constants have been computed to be

$$
\begin{aligned}
K_{XA} &= 302 \\
K_{YA} &= 278 \qquad \frac{(\text{microvolts})}{(\text{gamma})(\text{cps})} . \qquad (2) \\
K_{ZA} &= 315
\end{aligned}
$$

These coils are mounted on concrete slabs with their respective axes oriented in the X, Y, and Z directions. Each is guyed to its slab with cables to reduce vibration, and covered with a plywood house to keep off the wind. Their physical positions are shown in Figure 8.

There were two types of coils used in Puerto Rico. Those sensing the horizontal field components, H_x and H_y, had laminated mu-metal cores 72 in. long and were wound with approximately 30,000 turns of AWG 22 nyclad magnet wire. The core laminations are 0.032 in.; the effective core cross-section area is about 1.35 sq. in. An electrostatic shield encloses the windings of each coil. Each of the coils is securely mounted in a shielded wooden box for protection from the weather. Reference 3 contains a detailed description of the coils. Their sensitivity constants have been determined to be

$$K_{XM} = 149$$
$$K_{YM} = 156 \qquad \frac{(microvolts)}{(gamma)(cps)} . \qquad (3)$$

Figure 12 gives their equivalent circuit and parameters. Wire size, winding distribution, core configuration and other factors were optimized using The University of Texas CDC 1604 computer. To minimize thermoelectric and contact noise, the coils were wound with a continuous length of wire and have pure copper terminals. Figure 13 shows their appearance.

The vertical magnetic field component, H_z, was detected with an air core coil approximately 400 meters in circumference, wound with 100 turns of AWG 20 nyclad magnet wire; it was constructed by this

Laboratory for a previous project. Figure 14 shows the coil under construc-
tion. It was built in two, 50-turn sections so that the whole coil could not
be destroyed through damage to one part. The two pieces were laid on the
ground on top of one another and weighted at frequent intervals to prevent
wind vibration. No electrostatic shielding was used on the windings, and
field tests have shown the effects of electrostatic coupling with the ground
to be negligible at these frequencies with the differential input amplifiers
used. This coil, including the 830 ft. lead-in cable, has a dc resistance
of 1353. 5 ohms at 20°C and an inductance of approximately 1. 8 henrys.
It is self-resonant at 104 cps.

The coils at Puerto Rico were placed as shown in Figure 9, with
those measuring the H_x and H_y components carefully oriented in the proper
geographic directions. The H_z coil perimeter was surveyed and its area
computed from the surveying data as 131, 800 sq. ft. The coil sensitivity
constant was calculated for this area as

$$K_{ZM} = 7690 \quad \frac{\text{(microvolts)}}{\text{(gamma)(cps)}} \tag{4}$$

The boxes housing the mumetal core coils were set directly on
the ground after the surface on which they were to rest was smoothed and
leveled. Care was taken to disturb the soil as little as possible so that a
firm base would be available. Canvas sandbags, filled at a nearby beach,
were placed on the coils to prevent vibration. Each coil was weighted with
15 bags weighing about 75 lb. apiece. Tests made with the coils aligned

axially had indicated that the sandbagging was necessary, even though the total weight of a box and coil was about 200 lbs. Some further discussion of the problem of vibration in the coils will be found in the Noise Section.

The same type of lead-in cable was used at both stations. It contains three shielded, color coded, twisted pairs, heavily insulated with vinyl. The conductors are solid AWG 28 untinned, electrolytic copper. The cables were built to our specifications by Williams-Brand Rex Cable Company. They have proved very successful in minimizing thermoelectric and contact potential noise problems. The Austin lead-in cable is 1250 ft. long; the mobile unit uses an 830 ft. cable.

V. INSTRUMENTATION

A. The Electric Field

Essentially the same instrumentation was used to observe the electric field variations at Austin and at Puerto Rico in July; the Austin equipment was changed to be identical with that in Puerto Rico prior to the October session. The instrumentation used in October will be described first, then comments made on the differences in the equipment used at Austin in July.

Figure 15 is a block diagram of one channel of the electric field instrumentation. The other channel is identical. The series resistor in the upper input line is used to pad the electrode source impedance to the

nominal 600-ohm value required by the input filter. This filter, built to our specifications by White Instrument Laboratories of Austin, is flat within 1% from dc to 20 cps when properly matched by its source and load. It has rejection notches at 60 cps and 120 cps. The 60 cps rejection is about 50 db. Heavy filtering of the power line frequencies and their harmonics is virtually always necessary to prevent saturation of the input amplifier. Removal of the d-c potential generated by the earth-electrode contact is accomplished after the filter by inserting a series potential difference derived from a very stable mercury cell and adjusted by means of a 10-turn Helipot. This series voltage is adjusted so that the average input to the Offner input amplifiers is zero. The Offner 190 is a true differential input chopper carrier amplifier with a gain variable from about 300 to 1200. It was operated in this application with a gain close to 1000. The experience of this laboratory has been that the Offner 190, a vacuum tube amplifier with a 400 cps chopper, is the best commercially available amplifier for this purpose.

A Philbrick USA-3 operational amplifier is the next component. Its input and feedback elements are arranged to form a three pole - one zero filter. The frequency response can be easily varied by changing the values of capacitors C_1, C_2, and C_3. A center frequency gain of 10 was picked to allow use of the full dynamic range of both the Offner 190 and the USA-3 amplifiers when they are combined with the Offner Dynograph paper chart recorder. The Dynograph sensitivity can be adjusted in twelve steps from 10 millivolts/cm to 50 volts/cm. This arrangement provides a system

sensitivity which can be varied from 1 microvolt/cm to 5000 microvolts/cm by simple adjustment of the Dynograph, and allows operation from near the limit set by instrument noise to that set by saturation of the input amplifier. The gain charges performed in this manner produce no transient disturbances in the filter units. A wider range of sensitivities can, of course, be obtained by changing the gain of either or both the 190 and the Philbrick amplifiers, but it will entail the loss of several minutes of operation because of the large and lengthy transient disturbance which results. The system noise level is about 0.2 - 0.6 microvolts peak-to-peak.

The data can also be recorded on a seven-channel FM tape recorder so that it will be permanently available for filtering and time scale manipulations. The recorder input voltages are derived from feedback resistors in series with the Dynograph galvanometers, so that changes in the tape recorder sensitivity are accomplished simultaneously with changes in the paper chart sensitivities. By appropriate adjustment of the tape recorder level controls $\pm 40\%$ frequency deviation is obtained simultaneously with saturation of the paper chart recorder, allowing use of the full dynamic range of both instruments and preventing saturation of the tape recorder. The Austin station uses an Ampex FR-100A tape recorder; the mobile unit uses a Precision Instruments PS-207 recorder.

The Offner Dynograph paper chart recorder at Austin was delivered in October 1962; Esterline-Angus recorders were used until that time for continuous paper records. The remainder of the Austin system is as described above.

A wide variety of frequency responses were available. The response shapes were based upon extensive observations of the natural field activity, computation of numerous power spectra, and a considerable amount of experimentation in the field. Response curves for the Austin system are given in Figure 16; those for the Puerto Rican system are given in Figure 17. The same terminology will be used throughout this report to specify a particular response curve. For instance, consider the response 0.015 - 0.5 - 2.0 cps. The three numbers designate the nominal frequency positions of the three poles controlled by the USA-3 amplifier. Referring to the response curve, 0.015 cps is the lower 3 db point; 0.5 cps is the upper 3 db point or first downward break; and 2.0 cps is the second downward break. The curves of Figures 16 and 17 are the actual responses of the complete system and differ from the theoretical shapes, which include only the USA-3 response; this difference is small below 20 cps in the electric field systems.

B. The Austin Magnetic Field Instrumentation

The great difference between the coil impedances at Austin and those at Puerto Rico forced the instrumentation used at the two locations to be quite dissimilar. Figure 18 is a block diagram of one of the three identical channels of the Austin system. The signal from each coil is connected to the instrumentation by the special 1250-ft. shielded cable. At the instrumentation end of the cable is a 100 µf mylar condenser which, in combination with the coil impedance (see Figure 11), forms a two-pole low pass filter with breaks at approximately 0.07 cps and 2.6 cps for 60-cps rejection. A 100-ohm series

resistor and a 1.0 µf mylar capacitor are used to insert a calibration signal corresponding to a constant amplitude sinusoidal magnetic field. The Leeds and Northrup 9835-B amplifier is a very stable high-gain, low-noise dc amplifier which unfortunately uses a 60 cps chopper and has an upper cutoff at about 1.5 cps. The chopper frequency results in dc signals arising from any 120 cps input, forcing very heavy input filtering; the 1.5 cps cutoff naturally limits high frequency use of the coils. But the large coil impedance demands an amplifier with a very high input impedance, and the L&N is about as good as any available. After the L&N amplifier a dc bucking voltage, required to remove the contact and thermoelectric potentials from the coils, is inserted in a manner similar to that used in the electric field system. An Offner 190 amplifier set to a gain of about 1000 is the next unit. The coil shield is connected to the cable shield, and the latter and one conductor of the cable grounded at the L&N input, together with the shields on the cables going from the L&N through the bucking voltage unit to the Offner; the grounded conductor is common through the L&N. Great care is taken to assure that the only ground in each channel is at this point: see the "Noise" section.

The Philbrick USA-3 had two feedback impedance configurations used at different times: they are shown in Figure 18. Frequency response curves for the complete system are given in Figure 19. The Austin magnetic field instrumentation is calibrated in terms of field intensity in gamma.

The output of the USA-3 amplifier is recorded on the Offner Dynograph and on the magnetic tape recorder. By varying the Dynograph

and L&N gain settings, a center-frequency range of sensitivities from 40 gamma/cm to 0.002 gamma/cm can be attained. The instrument noise level is about 10^{-4} gamma peak-to-peak at the normal L&N gain of 10,000.

C. The Puerto Rican H_x and H_y Instrumentation

Mumetal core coils were used to sense two horizontal components of the magnetic field intensity variations. Figure 20 shows the H_x and H_y system block diagram. The electrostatic shield in the coil box was left floating except for a slight leakage path to ground; the coil shield was attached to the cable shield, which, together with one of the signal leads, was grounded at the preamplifier input terminals. A 4 μf mylar condenser and a 3.75 kilohm resistor connected across the input terminals, in combination with the internal impedance of the coil (see Figure 12), form a two-pole input filter with breaks at 1 cps and 10 cps. Any usual amount of 60 cps noise picked up in the coil is thereby reduced to a level which can be tolerated by the preamplifier. The 15 ohm resistor is used to introduce a calibration voltage into the coil.

The preamplifier was built by EERL especially for use with the mumetal core coils: it is a true differential input, chopper carrier amplifier with a response flat from dc to about 30 cps. The gain can be varied from zero to about 15,000; the chopper frequency is 94 cps. A circuit diagram is given as Figure 21. Considerable pains were taken to isolate the input transformer and chopper both electrically and mechanically and to eliminate or minimize any noise source over which control could be exercised. A noise level of 0.05 microvolts peak-to-peak in the 0 to 20 cps range was attained.

The usual USA-3 amplifier, connected as a two-pole filter, completes the frequency response shaping. Operational gain changes are provided by the Dynograph: the sensitivity range is from 0.1 microvolt/cm to 500 microvolts/cm, with the lower limit set by the USA-3 gain which is in turn limited by the preamplifier noise level.

The Puerto Rican system was calibrated in terms of microvolts output from the coils - all the original records are marked in that manner. System frequency response curves are given in Figure 22 in terms of relative voltage output; Figure 23 is a set of system response curves converted to absolute magnetic field intensity in gammas. There is a slight difference between the H_x and the H_y gamma calibration -- usually less than one db -- caused by the difference in coil constants and by component tolerances.

D. The Puerto Rican H_z Instrumentation

A block diagram of the instrumentation used with the 400 meter circumference air core coil sensing H_z is shown in Figure 24. The 5 μf mylar condenser at the coil cable termination brings the cutoff frequency of the coil and cable combination down to 20 cps. The White input filter is flat within 1% to 20 cps and has rejection notches at 60 cps (approximately 50 db) and at 120 cps -- it has essentially the same response as the input filter used on the electric field channels. A 15 μf capacitor at the output of the Offner 190 amplifier brings its cutoff frequency down to 20 cps. The USA-3 provides the final and variable response shaping. The Offner Dynograph gain control allows sensitivity settings ranging from 1 microvolt/cm to 5000 microvolts/cm,

referred to the voltage induced in the coil. The system noise level was between 0.2 and 0.4 microvolts peak-to-peak referred to the input, with the widest pass-band filter used.

Figure 25 is a set of relative voltage response curves; Figure 26 is a set of curves relating voltage to absolute field intensity in gammas.

E. Timing

The timing standard at both stations is a Westrex TS-3A chronometer, accurate to one part in 10^6 and capable of being synchronized with a standard such as WWV. Both relay closures and visual display are furnished by the clock each second, minute, and hour. An input unit is required to convert the relay closures into voltages which may be recorded on paper charts or on magnetic tape with the data. Figure 27 shows the circuit diagram of an encoder built by EERL for this purpose. A standard 60 cps output is also available. It is used in the mobile unit to provide standard frequency power for the tape recorder and the paper chart recorder drive motors.

The incidence of the chronometer second tick is synchronized with the incidence of the WWV second tick using the scheme shown in Figure 28. Very accurate timing is obtained in this way if a suitable correction is made for the WWV signal propagation time. During the tests timing error was held to less than one millisecond, referred to WWV time at the receiver.

Backup timing is provided by a filtering and pulse-shaping amplifier which accepts the WWV audio signal from a receiver, filters it about the principal frequency component of the second tick (20 cps), and converts

the signal to a pulse long enough to be recorded on the paper chart or on the tape recorder. Its use was not required during this operation.

April Weather was monitored during the countdown; as H-0 approached, a manual marker signal was inserted on the timing channel at certain reference times and at H-0 on the Puerto Rican records. These markers naturally do not have a very high degree of accuracy, but they give a gross indication of H-0 and provide rough timing in case of clock failure.

VI. NOISE

One of the most important considerations in making measurements of this type is the amount of noise present in the data. Unless the level, sources, and characteristics of the noise content are known, any data taken will be virtually worthless because one can never be really sure whether an occurrence on the data is real or merely system noise. The perversity of the noise encountered in these measurements is truly astounding, for very frequently it appears almost identical to signals normally received. The noise usually encountered might be considered as coming from five general areas: first, there is instrument noise arising in the amplifying and filtering apparatus; second, there is sensor noise due to characteristics of the detectors themselves; third is what might be called installation noise due to peculiarities of the whole apparatus and interactions between it and the environmental noise coming from various sources in the vicinity of the site;

and fifth is that noise which, falling back on the ancient definition, is simply the unwanted part of the input signal. Several of these sources and their noise contribution have been mentioned briefly in previous portions of this report.

A. Instrument Noise

Instrument noise was measured frequently and before every test by replacing each sensor, at the input to its amplifier, with a resistor whose value was near the internal resistance of that sensor. The filter with the widest available pass-band was inserted in each channel, and the largest peak-to-peak value of the equivalent input noise was read from the recording chart after several minutes had passed. The Offner 190 amplifiers in the E_x and E_y channels were biased halfway to saturation, using the input bucking voltage circuits, to detect chopper contact noise and variation in chopper dwell time under conditions worse than those encountered in normal use. Table 1 summarizes a typical test.

Assuming the apparatus to be in good condition, one may assume that for all practical purposes all the noise originates in the first amplifier in each channel. The noise voltages in Table 1 are, therefore, generated in the preamplifier; any attempt to reduce the noise component must be directed there. An Offner 190 Amplifier has an absolute minimum noise voltage of about 0.2 microvolt peak-to-peak, which may be attained only by careful adjustment and selection of the choppers and by hand picking the tubes and can be maintained only through frequent noise checks. To further reduce

Table I Instrument Noise Test Summary

System	Channel	Preamp	Source Resistance ohms	Filter* cps	Peak-to-Peak Noise microvolts	Normal Full Scale Sensitivity (mid band)	Noise Figure db
Puerto Rico	E_x	Offner 190	600	.015-2-10	0.3	100 μv	50
	E_y	Offner 190	600	.015-2-10	0.5	250 μv	54
	H_x	EERL	Open+	D	0.05	0.0535 γ	34
	H_y	EERL	Open+	D	0.06	0.0214 γ	24
	H_z	Offner 190	1500	.015-2-10	0.2	0.009 γ	54
Austin	E_x	Offner 190	600	.015-.5-2	0.8	1.7 mv	67
	E_y	Offner 190	600	.015-.5-2	0.6	1.7 mv	69
	H_x	L&N	20,000	.008-10	0.04	0.4 γ	50
	H_y	L&N	20,000	.008-10	0.04	0.4 γ	50
	H_z	L&N	20,000	.008-10	0.05	0.4 γ	48

*See response curves in Instrumentation Section

+ Input shunted with 4 μf and 3.75 KΩ filter components - See Figure 20.

the amplifier noise any dc component of the input signal is reduced to zero by the bucking voltage network, for variations in chopper dwell time will generate a noise signal if a dc component is present.

The Leeds and Northrup amplifiers have a noise level of about 0.04 microvolts peak-to-peak, which usually does not increase while the tubes are in good condition although occasionally one of the choppers will become noisy and require replacement. One of the disadvantages of these amplifiers is the 60 cps chopper frequency: the second harmonic of any 60 cps signal entering the amplifier is rectified and produces a dc component in the amplifier output. Another disadvantage is the 1.5 cps upper cutoff frequency.

The preamplifiers made by EERL for use with the mumetal core coils have a dc to 20 cps noise level of about 0.05 microvolts peak-to-peak. They are prone to deliver a sinusoidal noise signal at the beat frequency of the choppers when two amplifiers are operated in such a manner that there is mechanical vibration coupling between them. This problem was solved on the field trip by seating the amplifiers on individual cushions, and has since been eliminated by shock-mounting the choppers and driving them synchronously. An inherent noise is an 8 cps beat between the second harmonic of the chopper frequency (188 cps) and the third harmonic of the power line field (180 cps). This signal is small, however, and can be reduced to a tolerable value by means of suitable input filtering. A new model of the amplifier uses a 100 cps chopper frequency which puts the beats with all harmonics at 20 cps or above.

Mylar dielectric capacitors were used in all the filters and in critical parts of the coil amplifiers to prevent error caused by temperature variations and by residual (polarization) capacitor voltages.

It will no doubt have been remarked upon by now that all the data channels employ vacuum tube units for the first stage of amplification. The reason is simple: they are quieter in this frequency band than are the solid state amplifiers available at present.

B. Sensor Noise

The electrodes used in the electric field systems contribute some noise due to variations in contact potential. However, the rate of change of this potential is so low it is ordinarily not a problem, barring sudden water flooding of the electrode holes. Deterioration of the insulation on the lead-in wires and leakage to ground can present a more serious difficulty, which has been discussed previously. The only other noise contributors which have been encountered are due to the ground drying and cracking away from the electrodes, and a rather interesting diode effect discovered at the west electrode in Puerto Rico -- apparently caused by surface contamination of the cadmium rod. It was stopped by scraping the rod. Motion of the lead-in wires caused by wind or other factors can completely drown out the signal, but such motion is easily prevented. The passage of automobiles or very low-flying aircraft across the wires will induce a relatively large pulse-type disturbance.

The coils are extremely sensitive to vibration. It was necessary to weight the mumetal core coils with sandbags containing a total of about 1000 pounds of sand per coil to stop wind vibration and minimize the effects of ground vibration. Noise due to wind and some ground vibrations can be detected by aligning the coils axially while they are separated by 30 to 40 feet, recording their output voltages simultaneously through a relatively high cut-off filter, and watching for differences in the signals -- there should be no differences at all.

Obviously, the movement of any ferrous object in the vicinity of the coils will induce a voltage; but it is surprising how small the object need be -- small hand tools, slugs in radio coils, pants zippers, wrist watches -- and over what a distance its influence is felt. The passage of an automobile may be easily seen at a distance of hundreds of feet, the size of the disturbance depending on the speed of the car; and the flight of an airplane over the coil may be seen at altitudes of several hundred feet. The character of these disturbances is fairly easily recognized, and the lack of a similar signal on the appropriate E channel makes their detection easy.

Other noise sources which may be encountered, but which may be eliminated by proper coil design and construction, are thermal and contact potentials at points within the coil or at its terminals; battery cell voltages due to moisture leaking into the windings; and insulation leakage between the windings.

C. Installation Noise

This noise component arises from interaction between the measuring system and the environment. It is caused most often by the presence of more than one ground path in the system. When operating the system from a commercial power system one has little control over ground paths other than those in the instrumentation proper, unless an isolation transformer is used in the power line. It has been found best to limit the instrument chassis grounds to a single local ground rod, removing any grounding provisions from the line cords.

When operating a mobile station from a motor-generator set there is a different and completely new set of problems that occurs. One of the sources of trouble is interaction between the omnipresent 60 cps field from the commercial system and that from the portable generator. A beat between the fundamentals or between certain of the harmonics may occasionally be picked up in the sensors. It can be detected by varying the generator speed slightly, and can sometimes be moved out of the data pass-band by setting the generator frequency slightly above or below 60 cps. The sinusoidal wave form of a beat frequency is easily recognized but it may sometimes be confused with "pearl" or certain other naturally occurring types of oscillations. One must remain alert.

In the mobile unit, the bus body, the instrument racks, and the neutral of the three-phase generator are all common and are connected to a single copper ground rod set under the air concitioner water drip. Sporadic

ground paths sometimes occur due to freak events such as rainwater running over the bus or generator tires: these are usually seen as offsets in the data.

D. Environmental Noise

This type of noise is received through the sensors, but is due to local sources. The most troublesome noise source when working around populated areas is the grounding system of the local power distribution network, whose virtually continual load variations induce voltages within the data passband which are detected by the electrodes. There is not much that can be done about this other than moving the system to a more remote site.

Other sources of noise can be ground vibration such as that due to wave action when near a sea coast, or to highway traffic, that will induce a voltage in the coils.

E. Detection of Noise

Most system noise can be detected by simply comparing the records of the several components, which should be related by Maxwell's equations. To make this comparison easier we usually choose system frequency responses that make the E and H components look as nearly alike as possible. Also, one may compare E_x with E_y and H_x, H_y, and H_z with one another; for it is a rare signal that is perfectly aligned along one of the coordinate axes. If there is any signal evident in any one of the components which does not appear in some form in all the other components, it is almost certainly some type of noise.

Having described the detection of the obvious noise, it is necessary to weasel a bit on the more subtle cases where the suspect signal appears on all components and quite possibly -- even probably -- looks just like data. In such a circumstance there is simply no substitute for experience, which equips you to judge what types of signal and noise are likely to occur. However, in every new setup there are always several entirely new noise problems dealt out from an apparently inexhaustible stock. The best possible noise detector is, of course, a second station located some distance away, which can resolve almost all the noise questions.

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2.   Boothe, R. R., Jr., B. M. Fannin and F. X. Bostick, Jr.
      "A Geomagnetic Micropulsation Measuring System Utilizing
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      Texas, Electrical Engineering Research Laboratory Report
      No. 126, 25 May 1962.

SECTION OF TEXAS MAP SHOWING AUSTIN BASE STATION
LOCATION - TEXAS STATE HIGHWAY DEPT.

FIG. I.
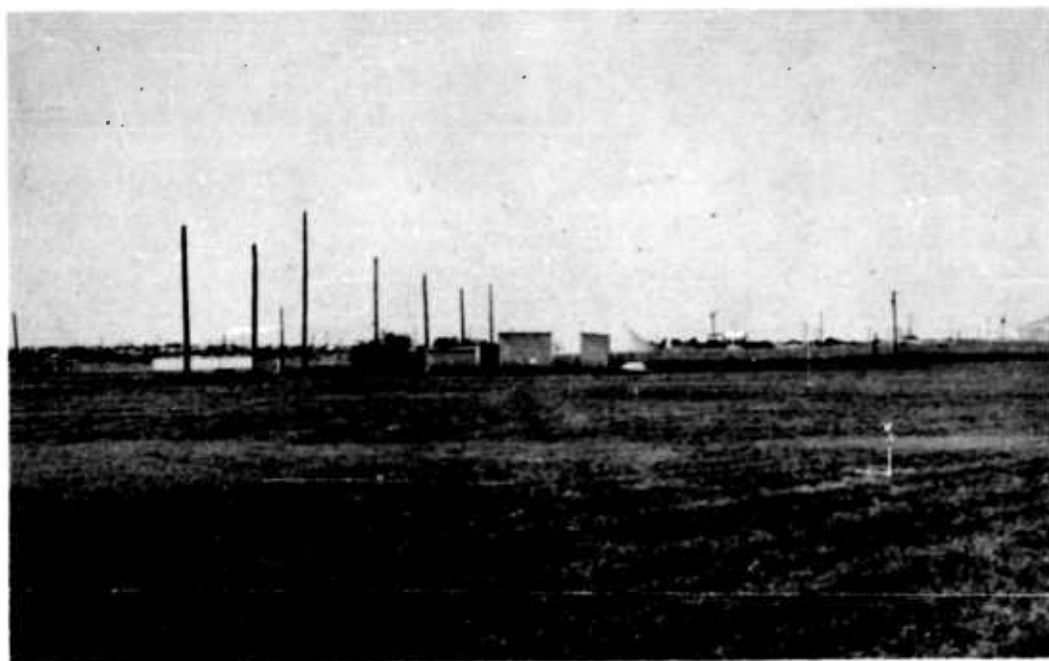
(a) LOCATION OF SENSORS, LOOKING SOUTH
TOWARD COIL HOUSINGS

(b) BASE STATION INSTRUMENTATION

THE AUSTIN STATION

FIG. 2.
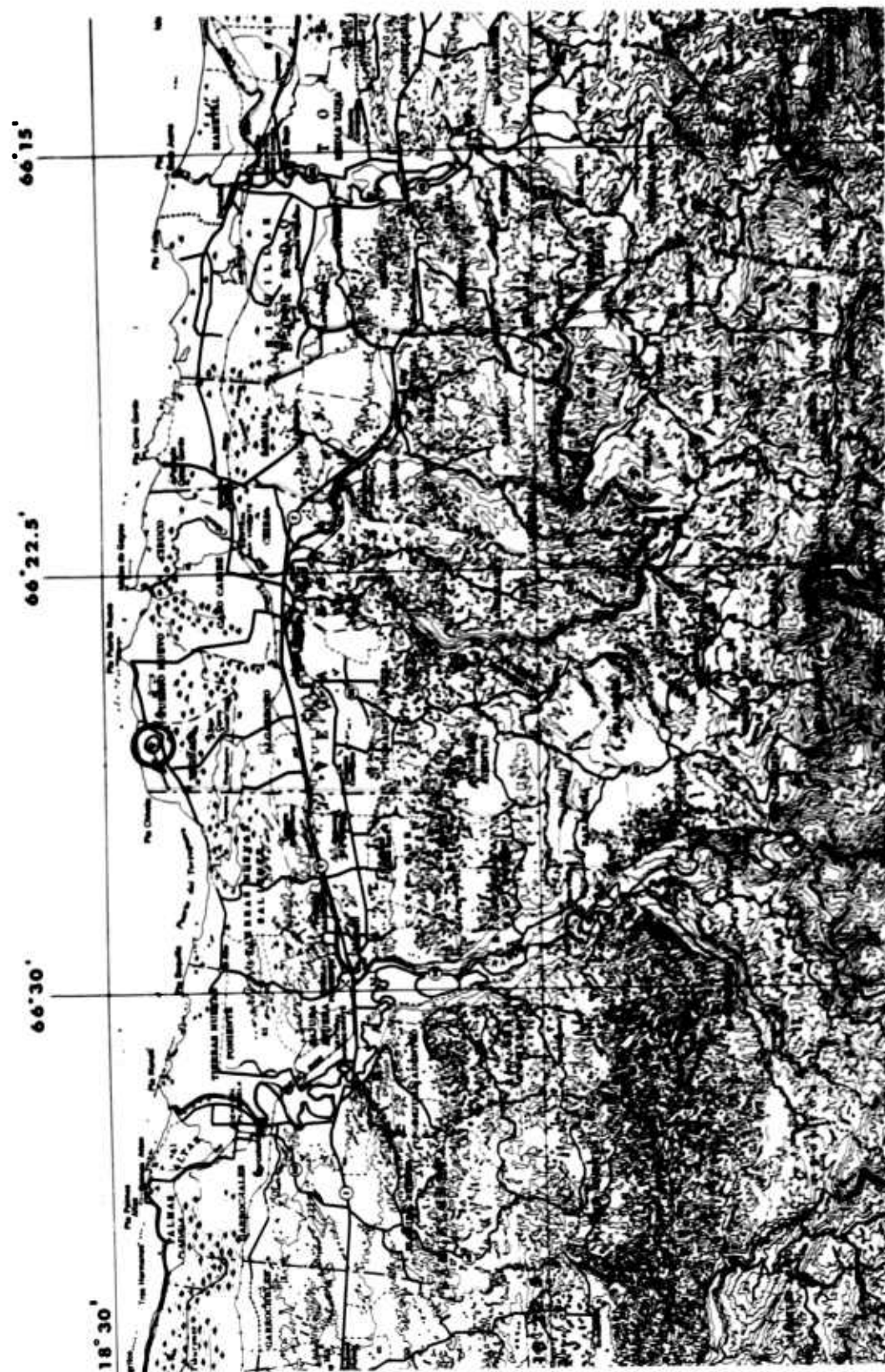
SECTION OF PUERTO RICAN MAP SHOWING MOBILE
STATION SITE — USCGS MAP

FIG 3
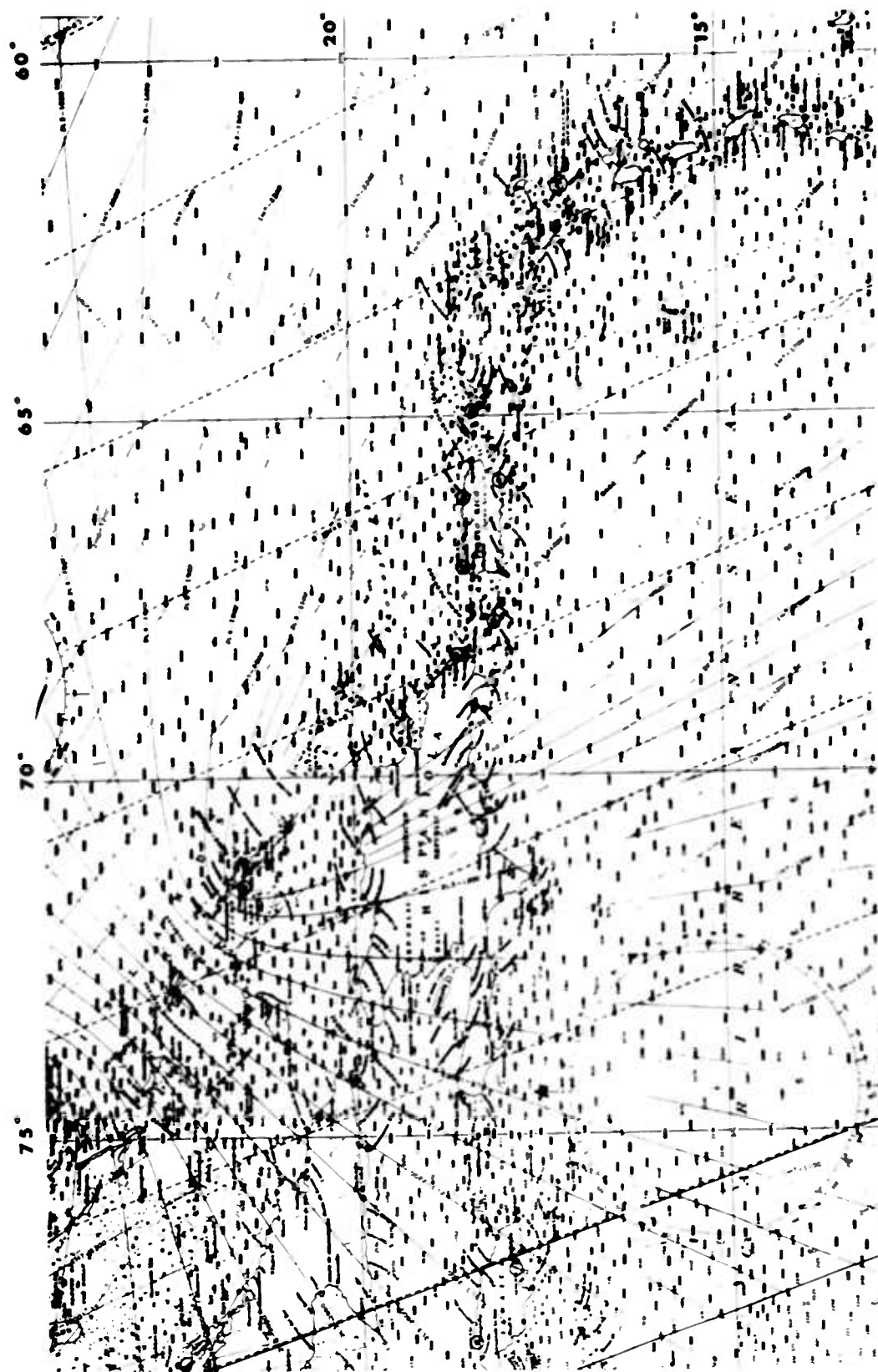
CARIBBEAN AREA — SECTION OF NHO MAP NO. 1290

FIG. 4
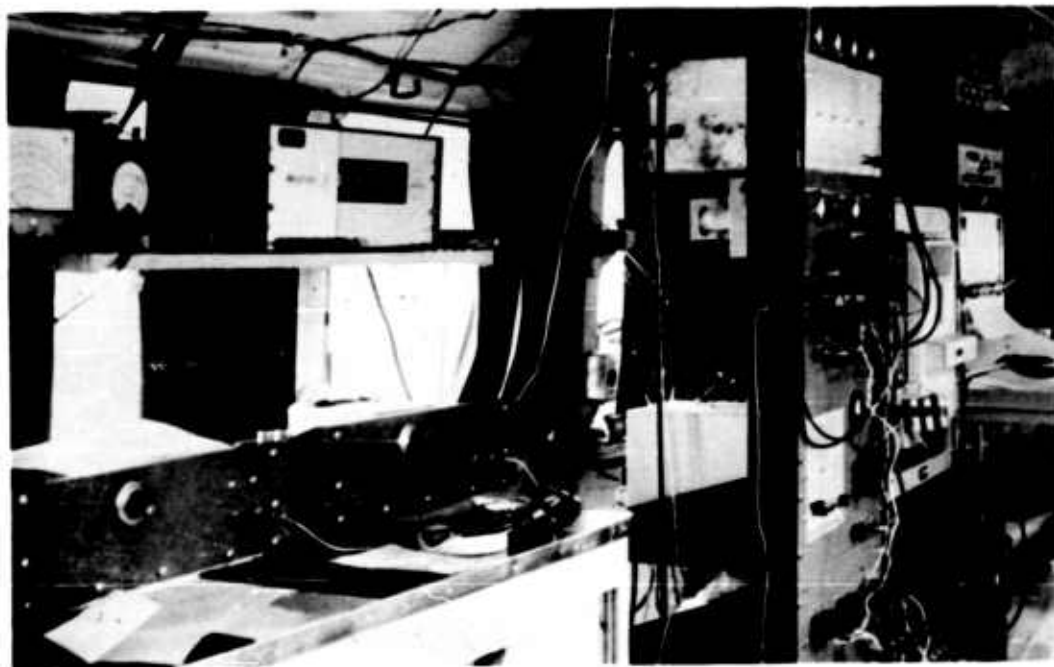
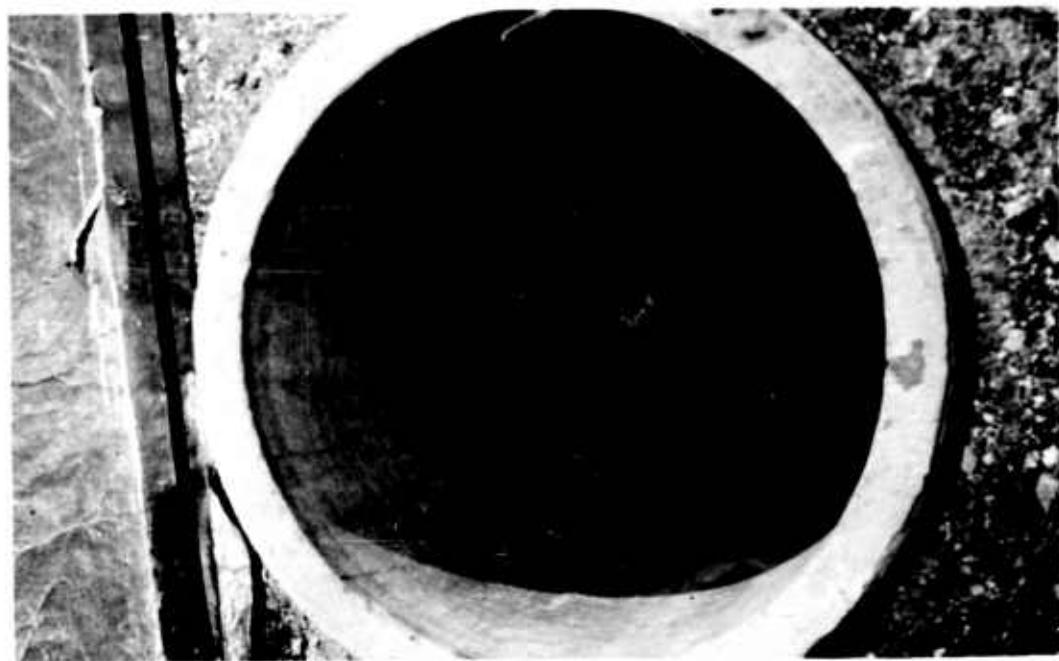(a) THE INSTRUMENTATION

(b) THE BUS
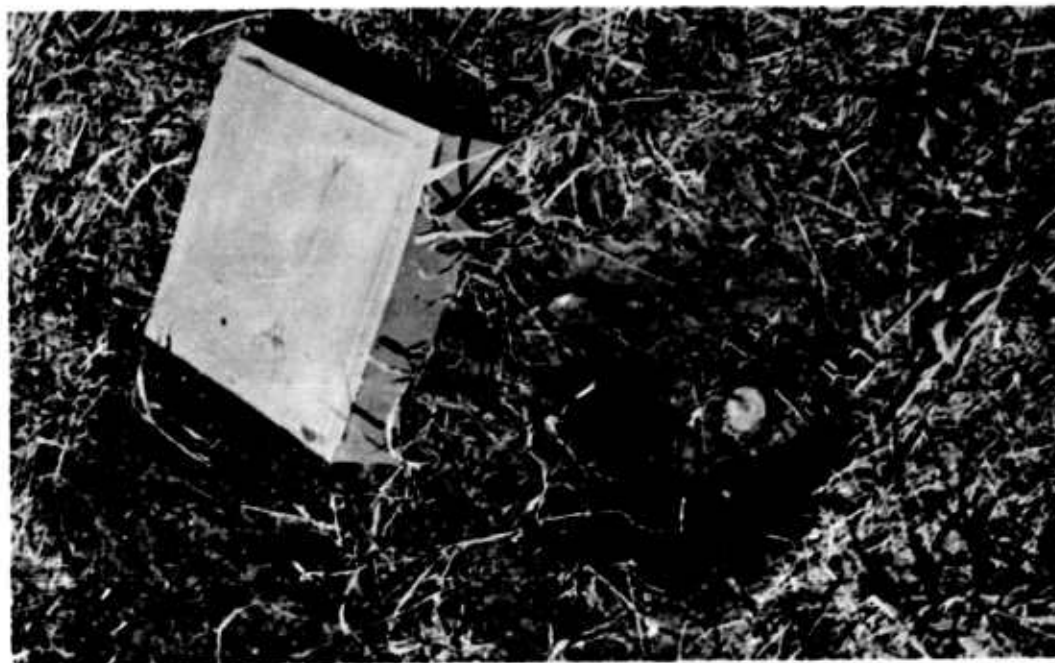
THE MOBILE UNIT AT TORTUGUERO

FIG 5

SEALANT

INSULATING SLEEVING

⌀ 10 RUBBER
STOPPER

$2\frac{3}{4}"$

Cd Cl₂

FILTER
CRUCIBLE

CADIUM
STICK

POROUS DIAFRAM

SOIL

$1\frac{5}{8}"$
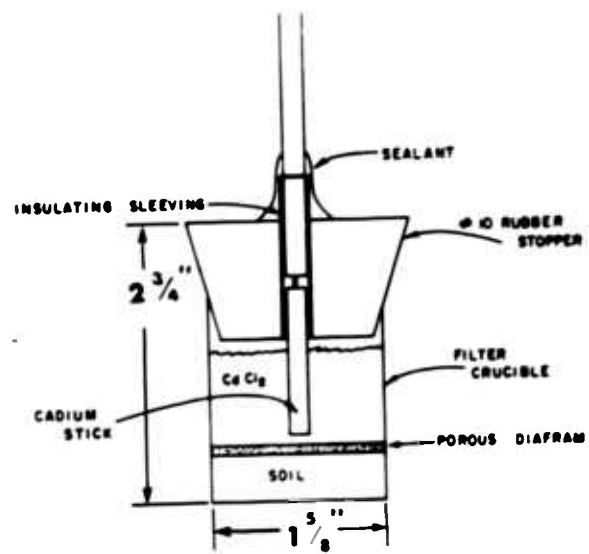
ELECTRODE FOR GROUND POTENTIAL MEASUREMENTS

THE ELECTRODE
FIG 6.

MOBILE

BASE

THE ELECTRODES INSTALLED
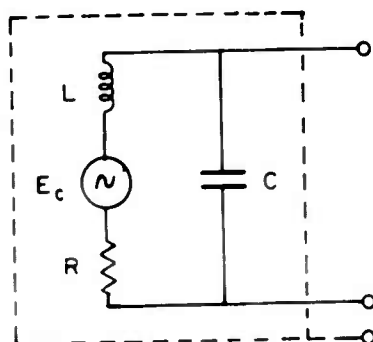
FIG 7
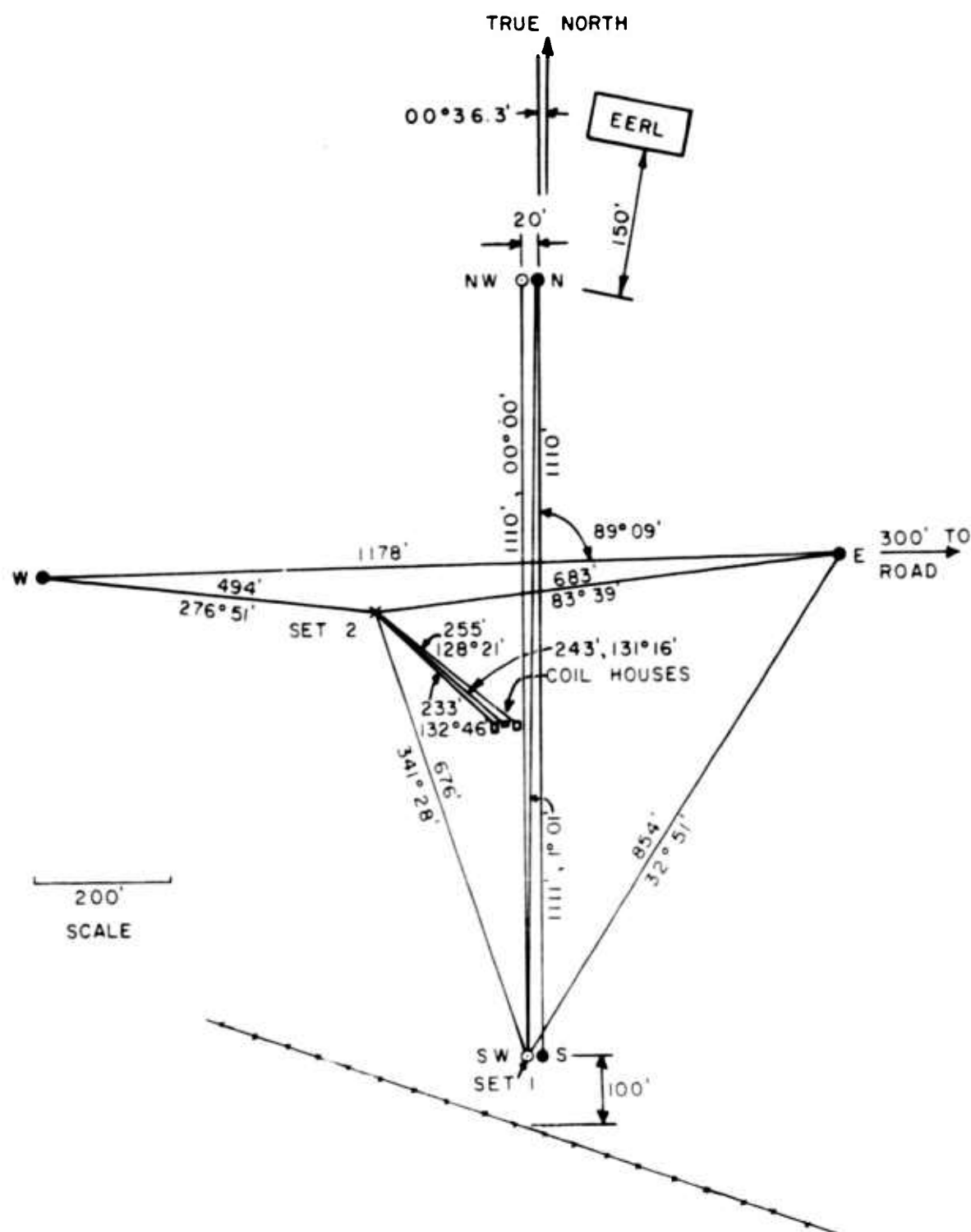
FIELD LAYOUT OF AUSTIN SENSORS.

FIG. 8.
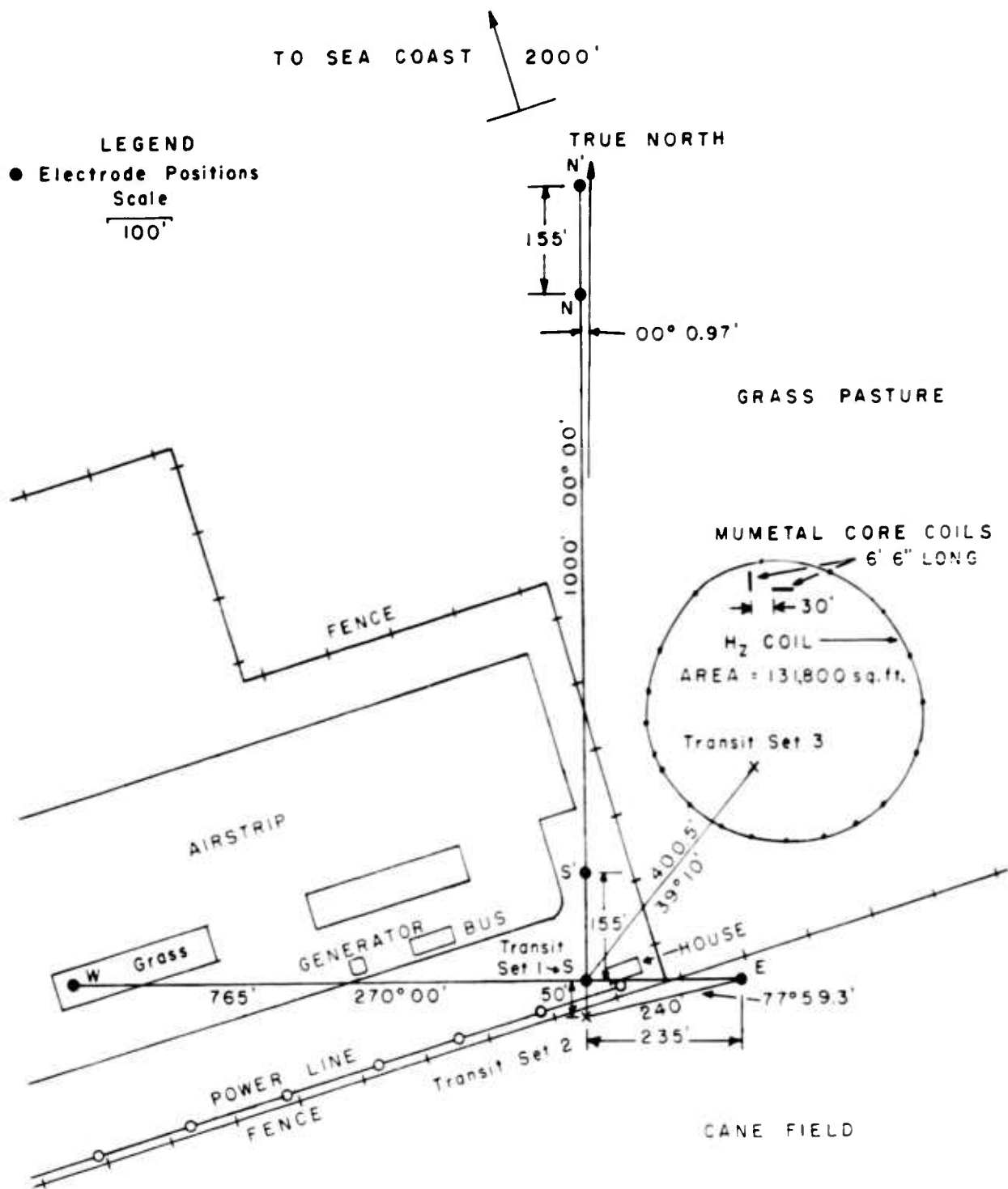
FIG. 9: FIELD LAYOUT AT PUERTO RICO SHOWING
SENSOR POSITIONING
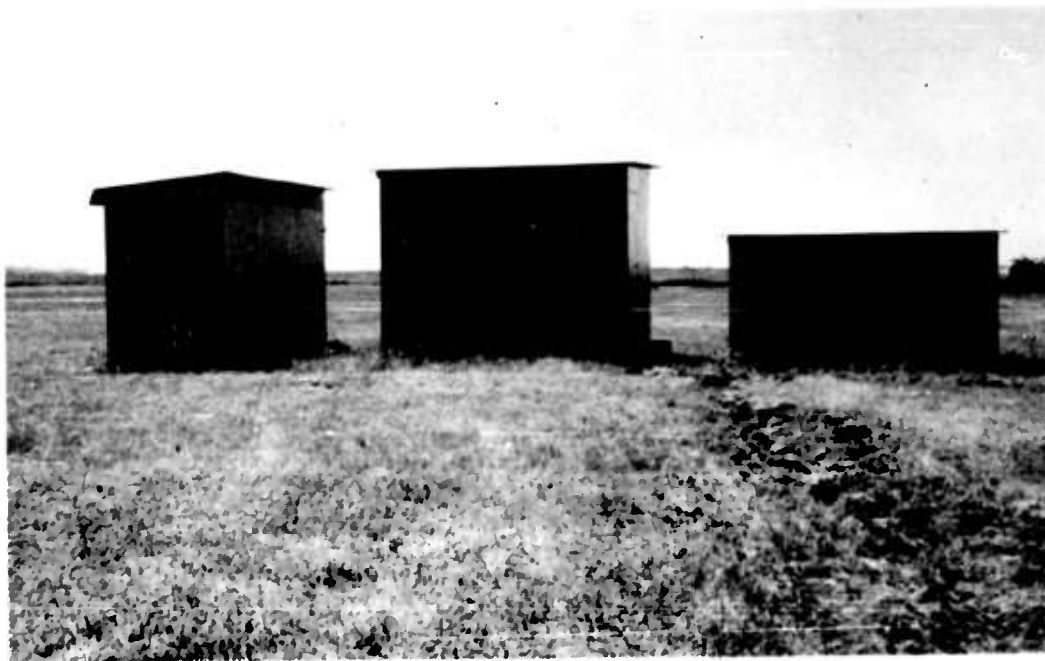
(a) HOUSINGS TO SHIELD COILS FROM WIND
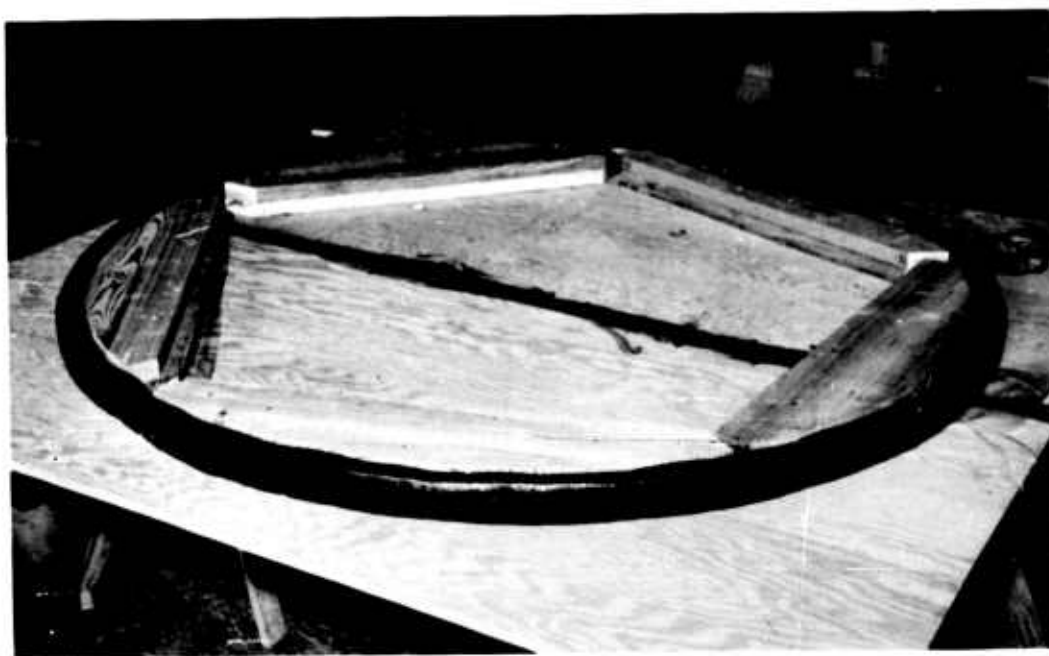
(b) A COIL UNDER CONSTRUCTION
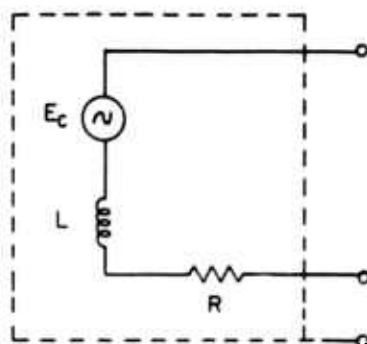
THE AIR CORE COILS USED AT AUSTIN

FIG 10.

Low Frequency Equivalent Circuit for Air Core Coils

Symbol	Units	Coil X	Coil Y	Coil Z
N	Turns	15,305	14,057	15,947
R	Ohms	20,200	18,600	21,100
L	Henrys	1,340	1,250	1,300
C	Microfarads	0.0352	0.0752	0.072
f_o	Self-resonant Freq cps	23.2	16.4	16.5
K_c	(Microvolts) / (gamma)(cps)	302	278	315

Coil Parameters

DATA ON AIR CORE COILS
AT AUSTIN

FIG. II.

Low Frequency Equivalent Circuit for Mumetal Core Coils

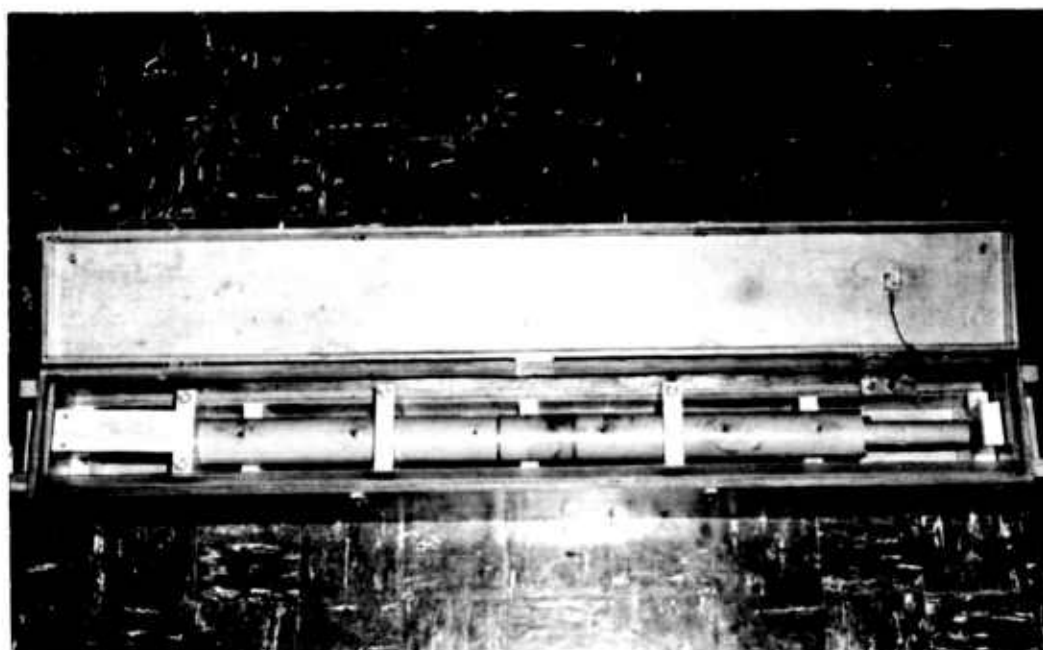| Symbol	Units	Coil X	Coil Y
N	Turns	30, 914	30, 842
R	Ohms	362. 0	366. 2
L	Henrys	660	680
f_o	Self-resonant Frequency cps	213	208
K_c	$\dfrac{\text{Microvolts}}{\text{gamma - cps}}$	149	156

Coil Parameters

DATA ON MUMETAL CORE COILS
AT PUERTO RICO

FIG. 12

(a) WINDING A COIL

(b) COMPLETED COIL MOUNTED IN SHIELDED BOX
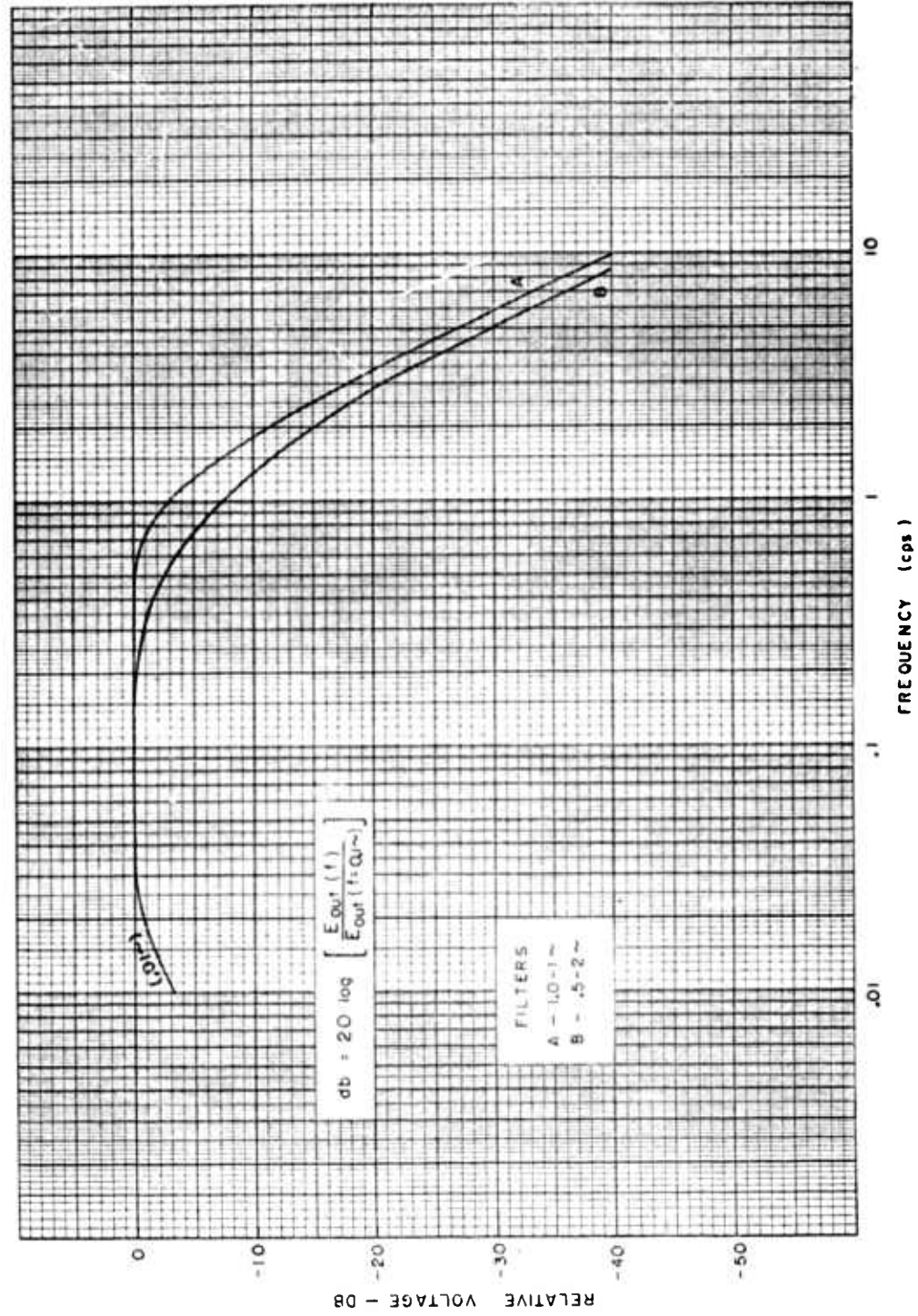
THE MUMETAL CORE COILS

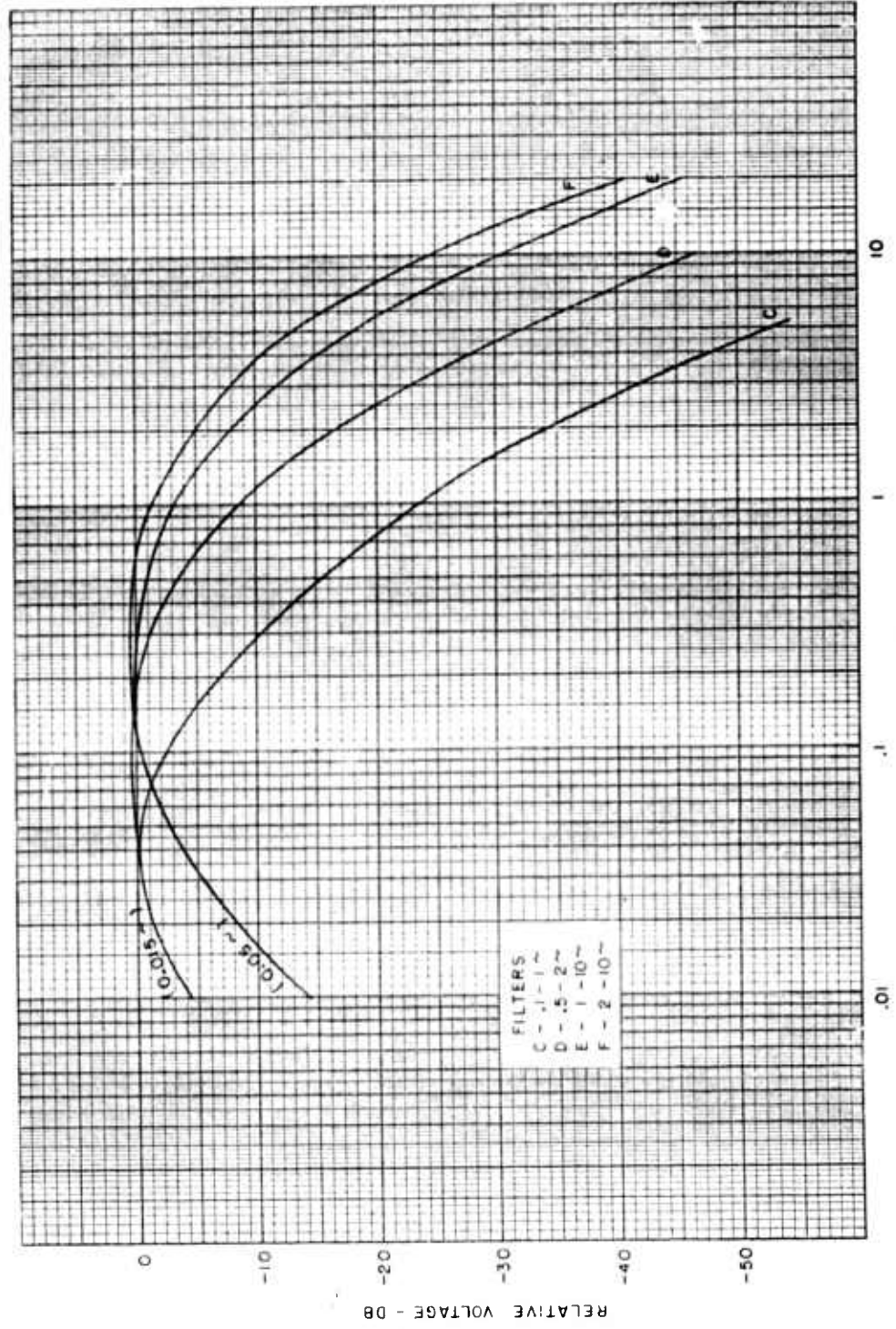FIG 13.

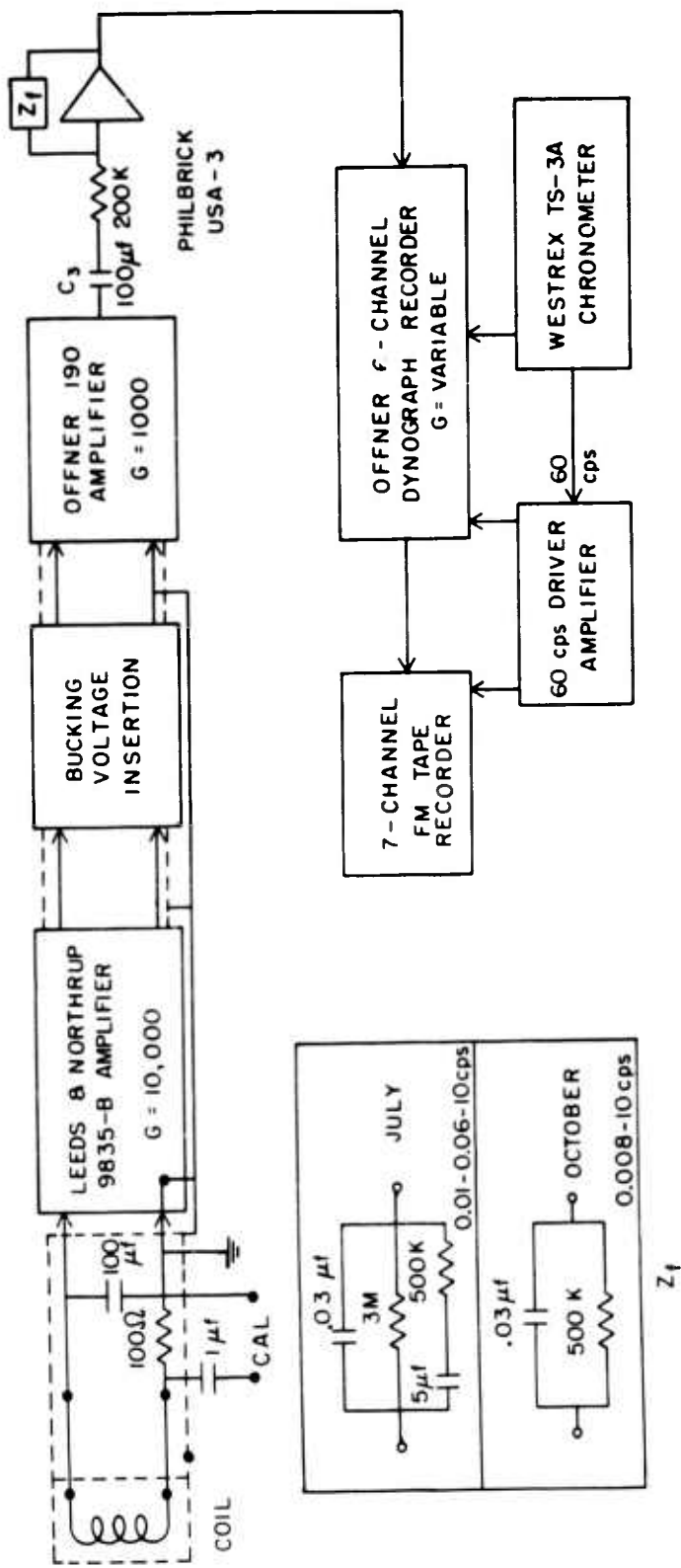(a) WINDING LAID OUT FOR WRAPPING

WINDING THE COIL

THE H_z COIL UNDER CONSTRUCTION

FIG. 14.

RESISTIVE
PAD

ELECTRODES

WHITE
60 cps
FILTER

BUCKING
VOLTAGE
INSERTION

OFFNER 190
AMPLIFIER
G=1000

C₃

100K

C_2

100K

100K

C_1

1M

PHILBRICK USA-3
G=10

OFFNER 6-CHANNEL
DYNOGRAPH RECORDER
G=VARIABLE

7-CHANNEL
FM TAPE
RECORDER

60 cps DRIVER
AMPLIFIER

60 cps

WESTREX TS-3A
CHRONOMETER

Response cps	$C_1 \mu f$	$C_2 \mu f$	$C_3 \mu f$
.01 - .1 - 1	0.82	3.0	160
.015 - .5 - 2	0.2	1.33	100
.05 - 1 - 10	0.08	0.3	32
.05 - 2 - 10	0.047	0.28	32
.01 - 1 - 1	1.0	0.25	160

BLOCK DIAGRAM OF ELECTRIC FIELD INSTRUMENTATION

FIG. 15

db = 20 log $\left[\dfrac{E_{out}(f)}{E_{out}(f=0\sim)} \right]$

FILTERS

A — 1.0 - 1 ~
B — .5 - 2 ~

RELATIVE VOLTAGE — DB

FREQUENCY (cps)

AUSTIN ELECTRIC FIELD RESPONSE

FIG 16.

FILTERS

C - .1 - 1 ~
D - .5 - 2 ~
E - 1 - 10 ~
F - 2 - 10 ~

FREQUENCY (cps)

MOBILE UNIT ELECTRIC FIELD RESPONSE

FIG. 17.

RELATIVE VOLTAGE - DB

BLOCK DIAGRAM OF AUSTIN MAGNETIC FIELD INSTRUMENTATION

FIG 18

FILTERS

A - .008 - .06 - 10~

B - .008 - 10~

into geo signal

FREQUENCY (cps)

RELATIVE GAMMA - DB
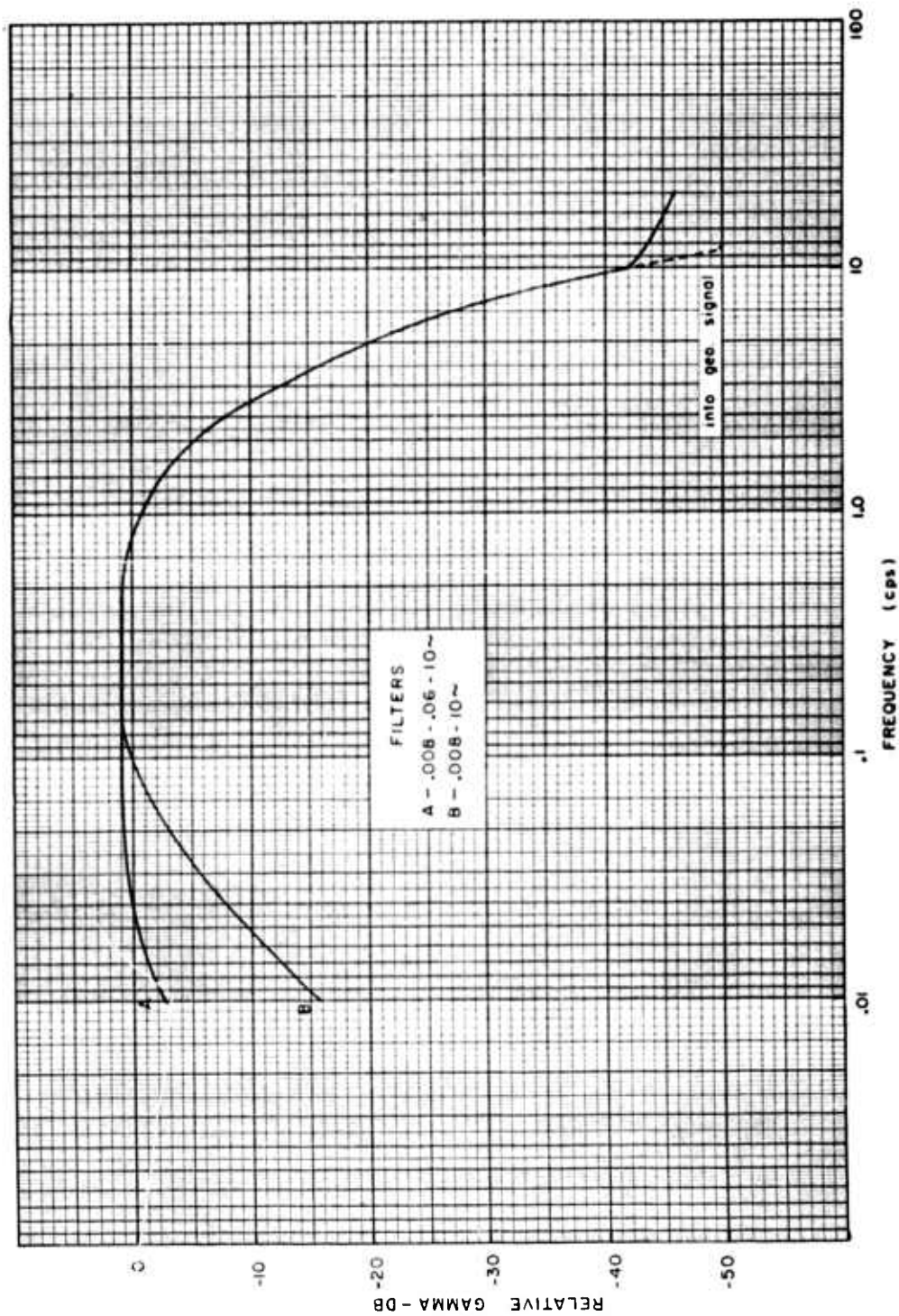
AUSTIN MAGNETIC FIELD RESPONSE.

FIG. 19.
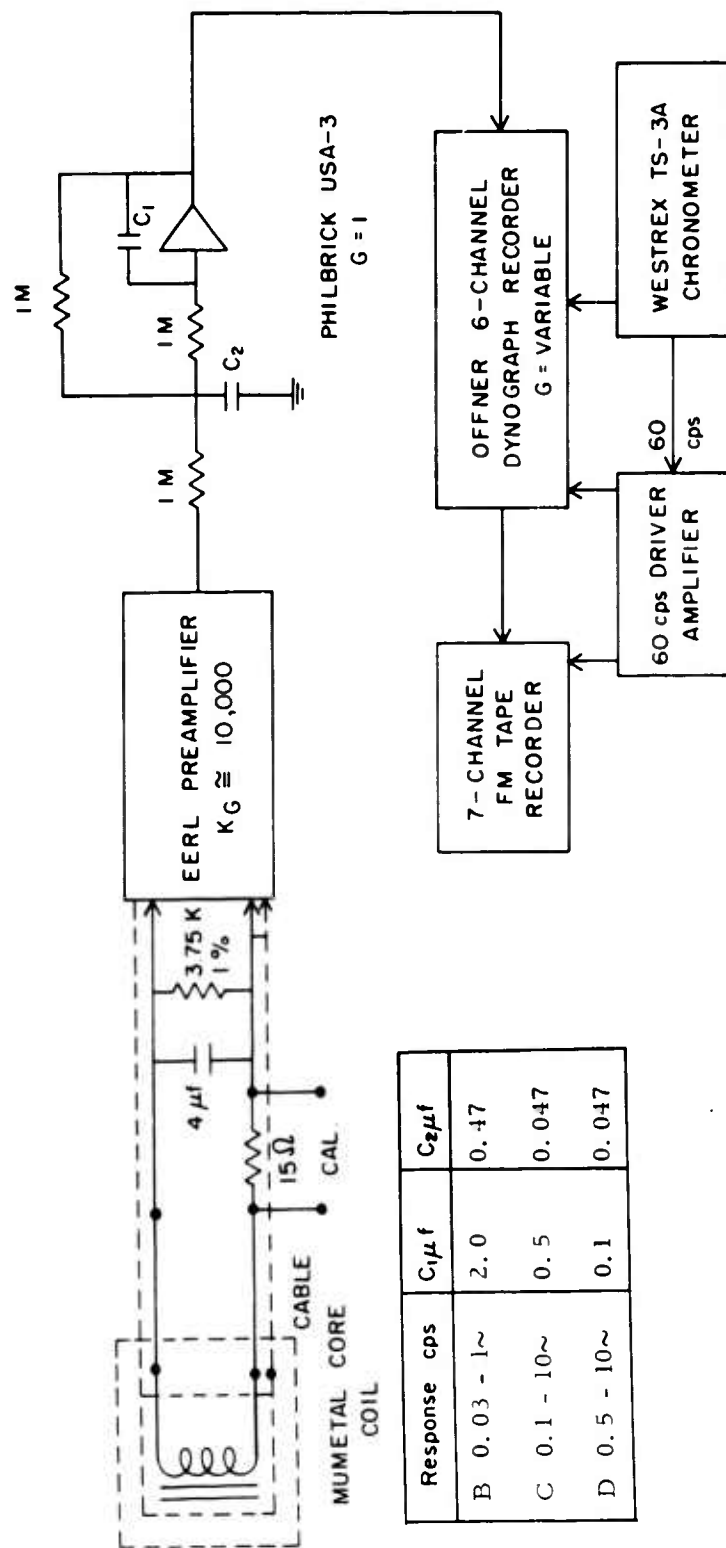
BLOCK DIAGRAM OF PUERTO RICAN H_x AND H_y SYSTEM

FIG. 20.

Response cps	$C_1\mu f$	$C_2\mu f$
B 0.03 - 1~	2.0	0.47
C 0.1 - 10~	0.5	0.047
D 0.5 - 10~	0.1	0.047
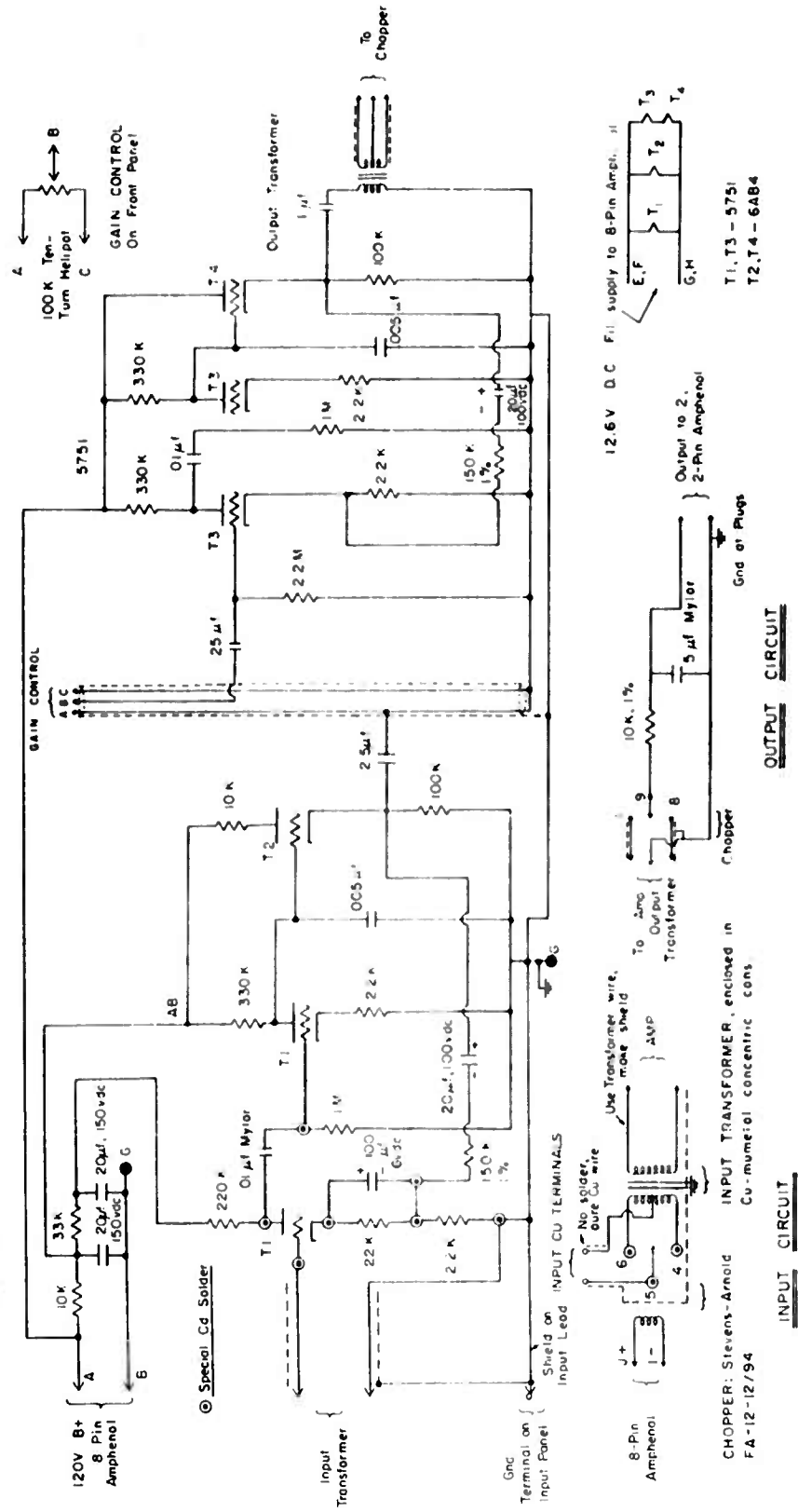
MUMETAL COIL PREAMPLIFIER

FIG 2'

FILTERS
B — .03 – 1 ~
C — .1 – 10 ~
D — .5 – 10 ~
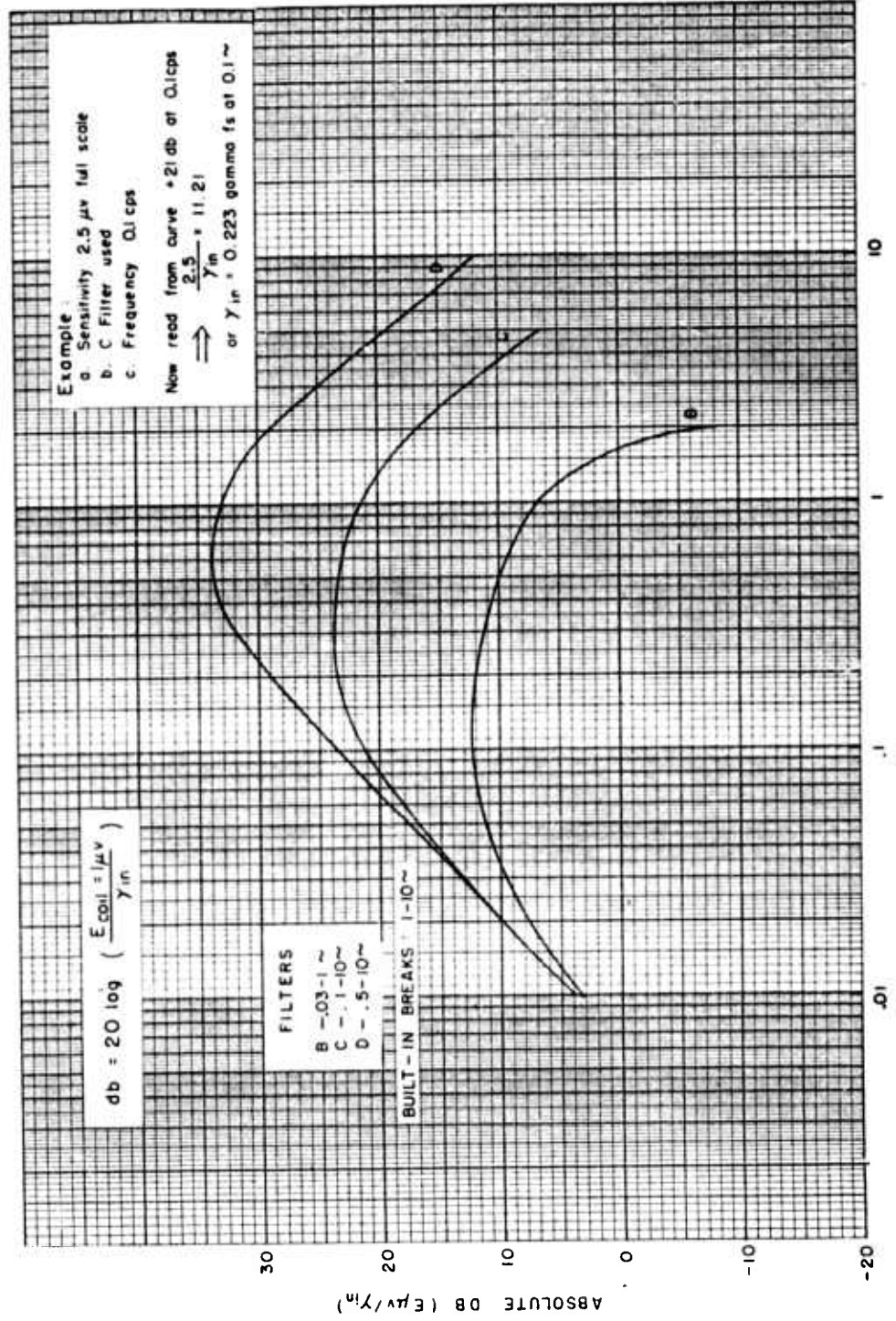
BUILT—IN BREAKS: 1–10~

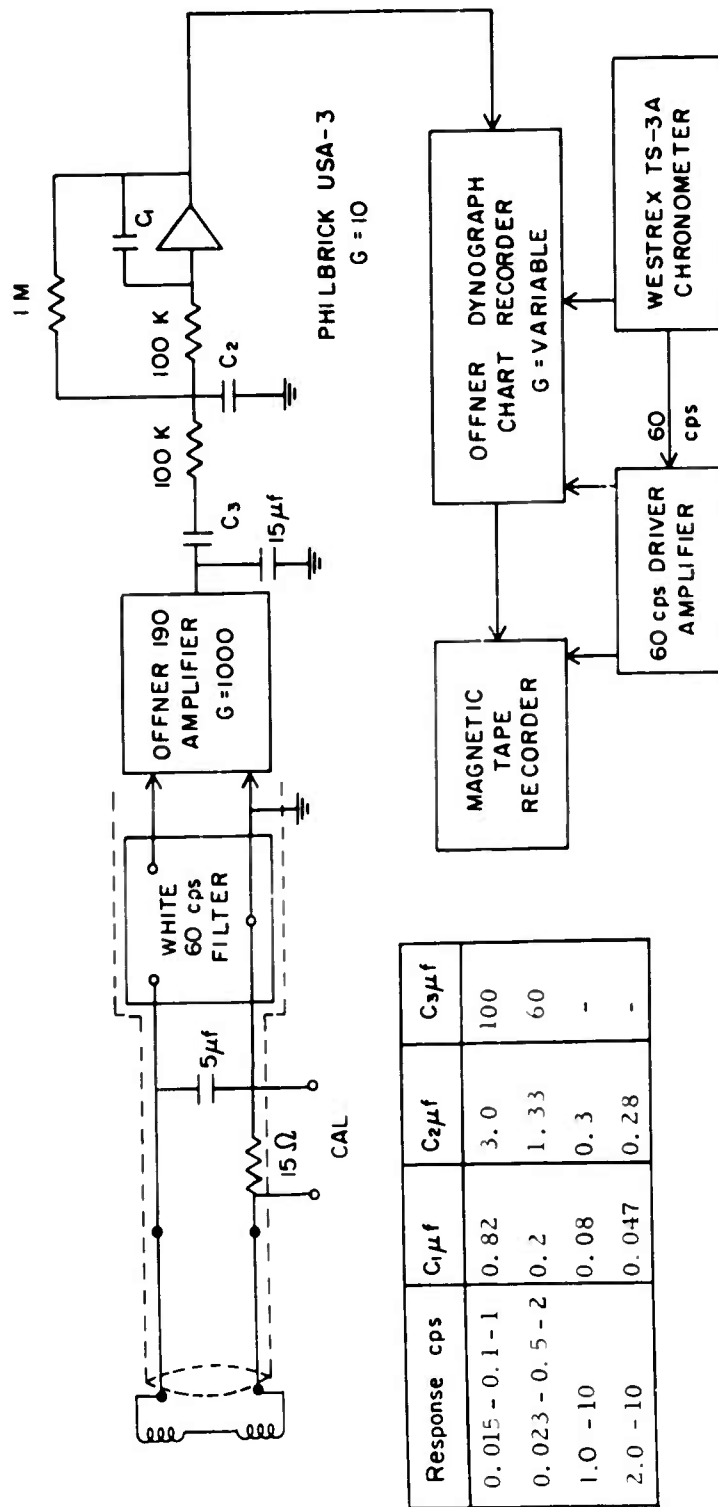FREQUENCY (cps)

RELATIVE VOLTAGE IN COIL—DB
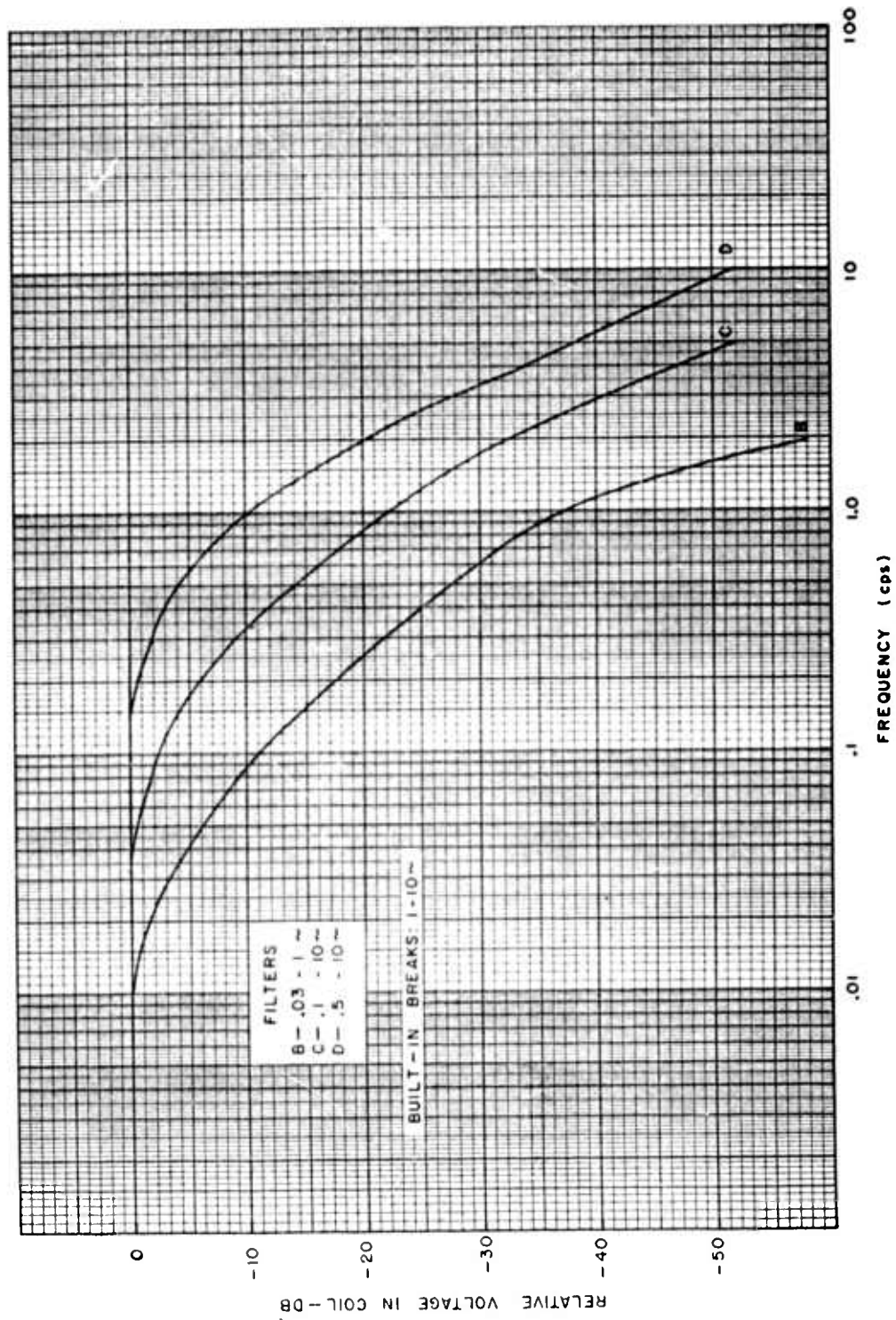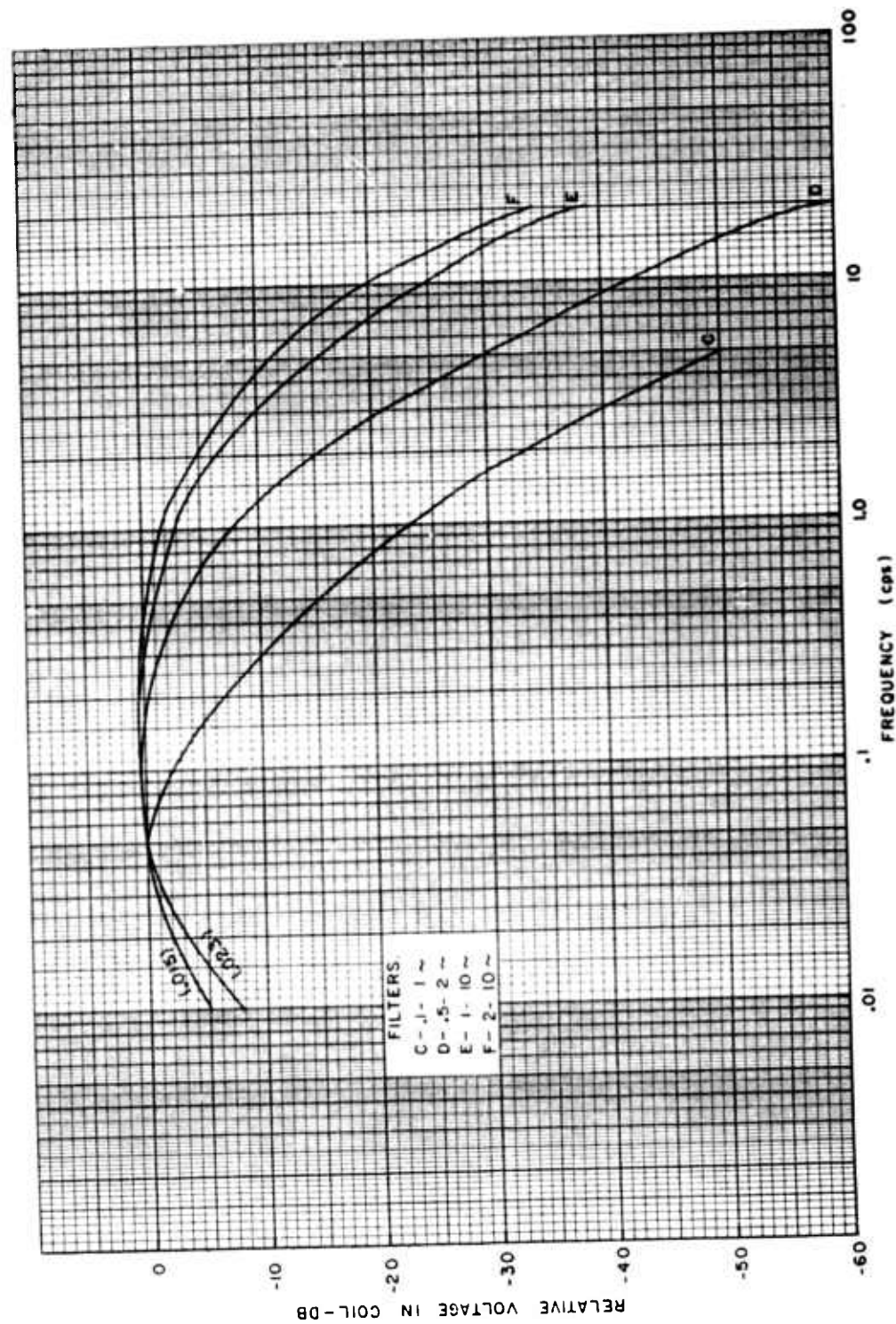
MOBILE UNIT H_X AND H_Y CHANNEL RELATIVE VOLTAGE RESPONSE.

FIG. 22.

MOBILE UNIT H_x AND H_y CHANNELS ABSOLUTE GAMMA RESPONSE

FIG. 23.

BLOCK DIAGRAM OF Hz SYSTEM AT PUERTO RICO

FIG. 24

Response cps	$C_1 \mu f$	$C_2 \mu f$	$C_3 \mu f$
0.015 - 0.1 - 1	0.82	3.0	100
0.023 - 0.5 - 2	0.2	1.33	60
1.0 - 10	0.08	0.3	-
2.0 - 10	0.047	0.28	-

MOBILE UNIT H_z CHANNEL RELATIVE VOLTAGE.

FIG. 25.

FILTERS
C - .1-1~
D - .5-2~
E - 1-10~
F - 2-10~

For example of use see FIG 23

FREQUENCY (cps)

ABSOLUTE DB (Eμv/γin)

MOBILE UNIT H$_z$ CHANNEL ABSOLUTE GAMMA.

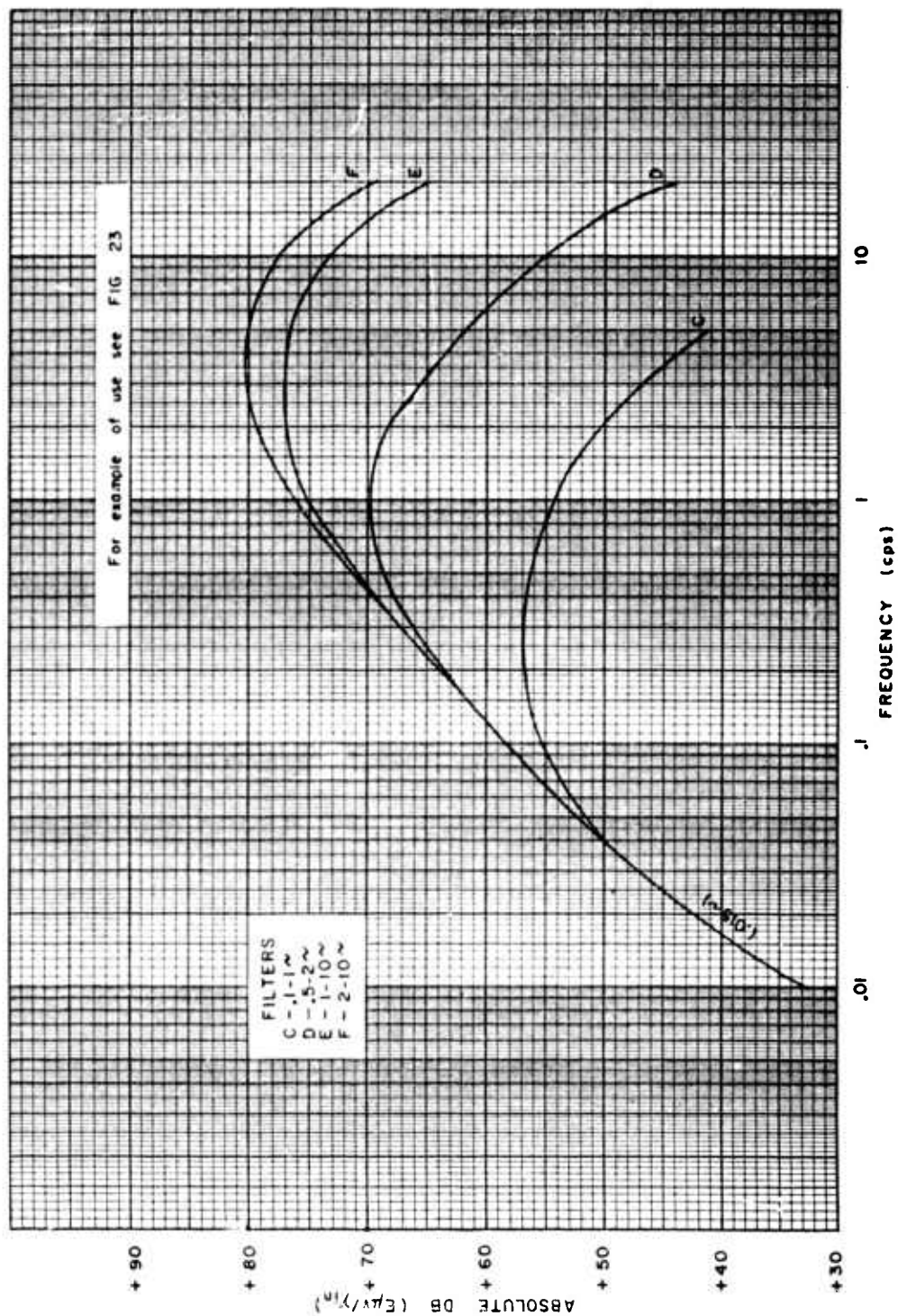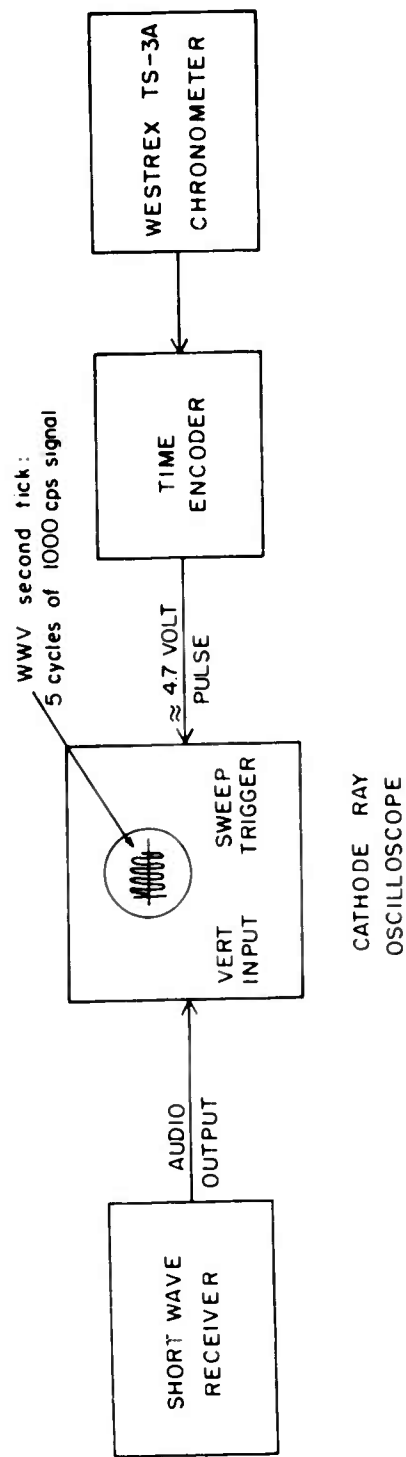FIG. 26.

TIME CODER FOR WESTREX TS-3A CHRONOMETER

FIG 27

BLOCK DIAGRAM OF CHRONOMETER SYNCHRONIZATION METHOD

FIG. 28.

UNCLASSIFIED